**US ARMY CORPS OF ENGINEERS, NEW YORK DISTRICT**
**New York, NY**

***Final Draft Report***

# NORTON BASIN/LITTLE BAY ECOSYSTEM RESTORATION HYDRODYNAMIC/WATER QUALITY MODELING

**Submitted by**
**HydroQual, Inc.**

**Under Subcontract to**
**O'Brien and Gere Engineers, Inc.**

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# EXECUTIVE SUMMARY

The U.S. Army Corps of Engineers (USACE), New York District and the New York State Department of Environmental Protection (NYSDEC), Region 2, are in partnership to construct several habitat restoration projects throughout the New York City area. One of the major habitat restoration opportunities identified by a joint USACE/NYSDEC interagency technical team (composed of USACE, NYSDEC, NYCDEP, NOAA, USEPA, NPS, USFWS) is the restoration of ecologically degraded borrow pits in Little Bay and Norton Basin, Jamaica Bay, Queens, NY. For this project, the New York City Department of Environmental Protection (NYCDEP) joined the team as a funding partner.

This report summarizes the modeling effort that was conducted in support of the project. The modeling effort was conducted in two phases. The first phase was a preliminary effort to develop the hydrodynamic/water quality model and determine the best data set with which to calibrate the model. The second phase of the project involved the actual calibration of the model and using the calibrated model to assess several recontouring scenarios. The scenarios involved recontouring Norton Basin and Little Bay to various depths in an effort to reduce or remove the vertical density stratification to improve water quality and habitat in the basins, which were shown in previous studies to be ecologically degraded.

Modeling showed that recontouring reduces vertical stratification in the basins, thus, improving dissolved oxygen levels and reducing the build up of hydrogen sulfide and ammonia concentrations in the bottom waters. Shallower recontouring depths result in greater mixing and greater improvement in water quality. The shallowest depth that was analyzed was recontouring Norton Basin and Little Bay to a depth of 4 m below mean sea level (MSL) in the bottom waters, or 10.5 ft. below mean lower low water (MLLW). This depth was chosen because it is shallow, yet it should be deep enough to not allow enough light to penetrate to the bottom and allow the growth of the nuisance macro-algae *Ulva lactuca*.

The Norton Basin and Little Bay appear to react independently of one another. Bathymetry changes made in one basin do not appear to positively or negatively affect the water quality in the other basin in a substantial way.

A shear stress analysis showed that recontouring Norton Basin and Little Bay to a depth of 4 m below MSL (10.5 ft. below MLLW) does not result in producing shear stresses that are great enough to resuspend bottom sediments under the year 2002 conditions.

Filling Norton Basin and Little Bay to a depth of approximately 4 m below MSL (10.5 ft. MLLW) is the recommended alternative. However, all recontouring scenarios showed improvement in water quality over current conditions. A sloped contour from the head end to the mouth, with depths between three and six meters, would also be an appropriate solution. It is important to keep in mind that the mouth of Norton Basin should be made deeper than any portions of the interior basin in order to keep areas of stagnant water from developing. Deep areas could lead to poor vertical mixing and poor water quality such as is currently observed in these basins.

# SECTION 1

# INTRODUCTION

The U.S. Army Corps of Engineers (USACE), New York District and the New York State Department of Environmental Protection (NYSDEC), Region 2, are in partnership to construct several habitat restoration projects throughout the New York City area. One of the major habitat restoration opportunities identified by a joint USACE/NYSDEC interagency technical team (composed of USACE, NYSDEC, NYCDEP, NOAA, USEPA, NPS, USFWS) is the restoration of ecologically degraded borrow pits in Little Bay and Norton Basin, Jamaica Bay, Queens, NY, shown in Figures 1-1 and 1-2. For this project, the New York City Department of Environmental Protection (NYCDEP) joined the team as a funding partner.

The first step in this process was to characterize the conditions in Norton Basin/Little Bay to determine if the waterbodies were degraded and if so to what degree. A phase 1 environmental baseline sampling program was conducted in Norton Basin/Little Bay, and two reference areas in Jamaica Bay (Grass Hassock Channel and the Raunt) during 2000-2003. This sampling program included the following:

1. Background literature investigation.
2. Detailed acoustic bathymetry.
3. Water quality.
4. Hydrodynamics.
5. Sediment physical characterization and geochemistry.
6. Sediment contaminant bioassay/bioaccumulation studies.
7. Benthic invertebrate community characterization (grab, SPI, multivariate analysis).
8. Fish surveys (gill nets and otter trawls).
9. Fishery bioacoustics.

Phase 1 sampling and analysis was conducted by the USACE (the District and ERDC) and the NYSDEC, via contract and in-house work. A brief Summary Report (BVA, 2005) and a detailed Technical Summary Report (BVA, 2005b) on the entire baseline study program have been completed and are available from the USACE.

Thus, the areas in question have been intensively sampled and analyzed over the past 5 years by the USACE, the NYSDEC and others, and a thorough ecological baseline survey and summary reports have been prepared and made publicly available for review. These reports describe in exhaustive detail the data and logic utilized by the interagency team which was subsequently used by the NYSDEC in their decision to issue a Findings Statement in October 2004 stating that the borrow pits in question are ecologically degraded and would likely benefit from active restoration efforts. As a result, phase 1 of the project was


Figure 1-1. Study Area


Figure 1-2. Norton Basin and Little Bay

completed with the decision to find the borrow pits in question ecologically degraded based on the baseline data. Much of the poor water quality that exists in these water bodies is due to their geometry. The deep borrow pits contribute to poor circulation and the development of vertical density stratification. This traps water with low dissolved oxygen levels at the bottom. It is believed that recontouring these borrow pits will improve circulation, and by doing so, water quality and habitat will improve. Hydrodynamic and water quality modeling will provide some insight as to what kind of improvement or worsening of water quality could be expected due to recontouring the borrow pits.

There are two more phases to the project, namely, the actual construction and post-construction monitoring to determine the level of success in achieving the restoration goals established by the agencies. However, in order to begin phase 2, several items are required by law, policy and practical engineering necessity. In approximate chronological order (among other items to be identified in the future) these steps include:

1. Development and application of a HD/WQ model for the project area.
2. Sediment transport analysis to predict entrance channel shoaling rates and volumes.
3. Development of an overall implementation plan to carry the project through to completion.
4. Conceptual restoration plans.
5. NEPA compliance.
6. Coordination with all concerned agencies and the public.
7. The acquisition of all required permits and approvals.
8. Plans and Specifications.
9. Development and prior approval of a post-construction monitoring plan.

This report presents the results of the first step.

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## SECTION 2

# METHODOLOGY

The modeling was split into two phases due to the available funding and schedule. The first phase was the development of a preliminary model. The tasks involved in this first phase are outlined below. The second phase of modeling involved calibration of the model and modeling projections, which are also outlined below.

Phase 1: Initial Coordination/Development of Work Plan and Preliminary Model

The phase 1 tasks were as follows:

a. Analyze appropriate data to determine which year HD/WQ model will be calibrated against.
b. Develop model grid.
c. Begin compiling necessary model inputs
d. Develop a partially calibrated model to the point that it can provide preliminary run results.
e. Deliver a presentation to the District, the NYSDEC and the Port Authority of New York and New Jersey (PANYNJ) on the results to date of the above data analysis, model grid and the framework/rationale for the model to be developed for the project. A discussion of what steps would be next to fully calibrate the model would then be conducted. The presentation will also include ample time for general discussion of the overall modeling effort by all participants.

Data were obtained from Barry A. Vittor and Associates (BVA) and NYSDEC for analysis. The majority of water quality and hydrodynamic data were collected during 2001 and 2002, which narrowed the choice of calibration year to these two options. Further analysis showed that the majority of the temperature, salinity and dissolved oxygen (DO) data obtained from BVA were collected during 2001, but the majority of the nutrient and chlorophyll-a data were collected during 2002. The NYSDEC data included temperature, salinity and DO data during the summer and fall of 2000 through 2002. To make the final decision as to which year to model, an analysis of annual rainfall was conducted. Figure 2-1 presents the annual rainfall data collected at John F. Kennedy (JFK) International Airport for the years 1969 through 2004. The data show that 2001 was one of the driest years of the rainfall record examined, and 2002 was very close to the median rainfall. Based on the water quality and rainfall data a decision was made to use 2002 as the calibration year because it would better represent average conditions.

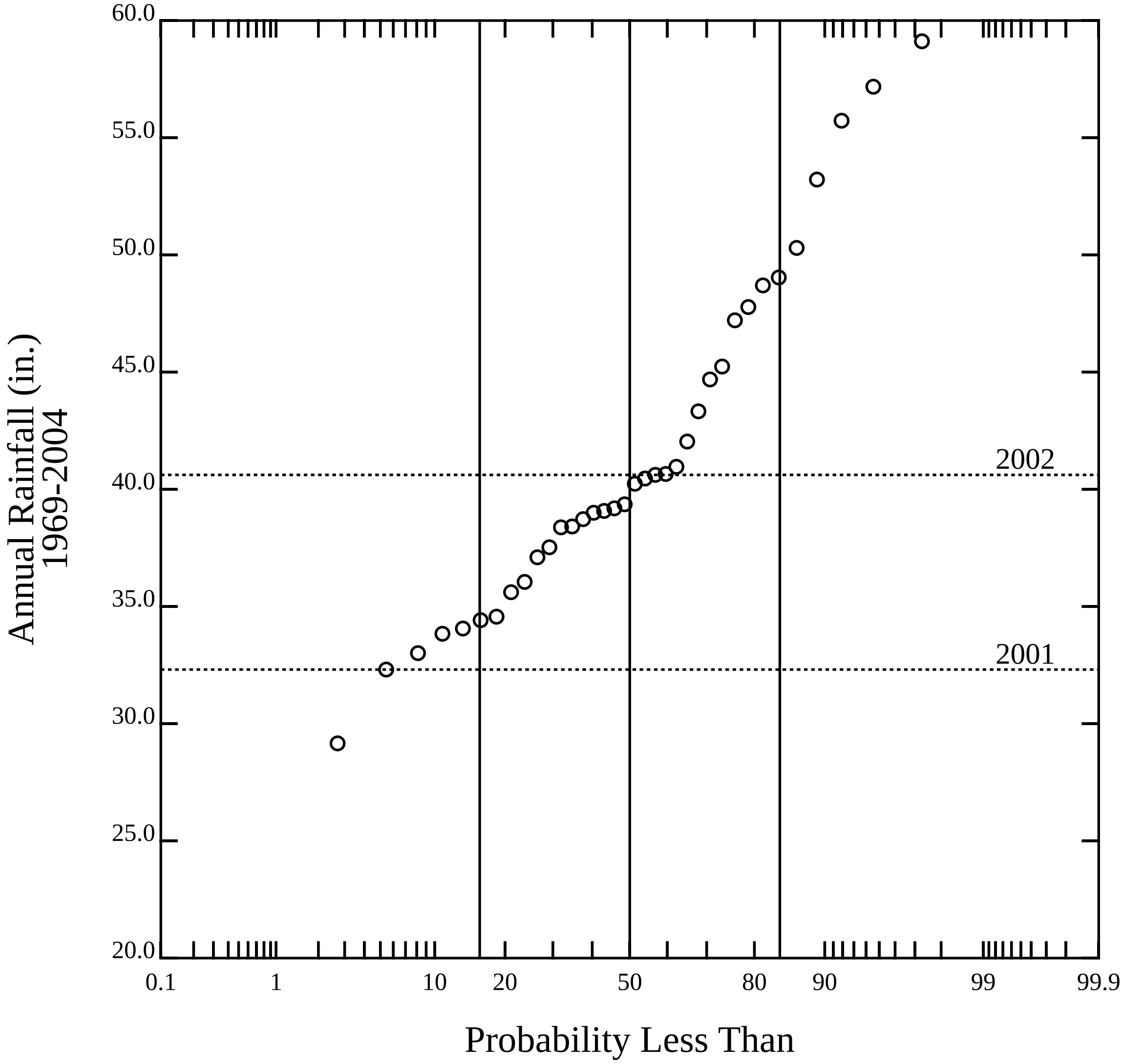



Figure 2-1. JFK Airport Rainfall Data

The data from 2002 show a number of features within Little Bay and Norton Basin (Figure 2-2). In general, the shallow areas of the basins have fairly good water quality in terms of DO. Deeper areas tend to have lower DO. An unexpected feature in the data is that despite their proximity and similar depths, Little Bay has much more density stratification than Norton Basin. During the summer time, Norton Basin may have 2-4 °C of temperature stratification and very little salinity stratification. Conversely, Little Bay has approximately 18 °C of temperature stratification and 2.0 ppt of salinity stratification. These different density stratification conditions result in different water quality conditions. Since Little Bay is more stratified, dissolved oxygen levels stay lower for longer and ammonia concentrations become much higher. The result is poorer habitat conditions in Little Bay than in Norton Basin.

The next step was to develop a model grid. High-resolution bathymetry data, in areas deep enough for the survey boat to pass, were collected in Norton Basin/Little Bay as part of the sampling program. Bathymetry data for other portions of the model were available from interpreting NOAA charts, aerial photographs and personal communications, (Will, 2006). Norton Basin and Little Bay have deep borrow pits with very rapid changes in depth. The first attempt to develop a model grid to reproduce the geometry of the domain is presented in Figure 2-3. A closer look at the Norton Basin/Little Bay grid is presented in Figure 2-4. The domain covers from Silver Hole Marsh to Thurston Basin. The Estuarine, Coastal and Ocean Model (ECOM) was used for the hydrodynamic modeling. The model grid was developed as a sigma-layer grid in the vertical direction such that each segment in the model had 10 layers no matter what the depth of the location. The fine segmentation was developed to counteract what is called "upslope mixing" that can occur with a sigma-layer model. Upslope mixing occurs when a shallow area is next to a deep area. Because each area of the model has the same number of layers, the bottom layer of the shallow segment can communicate with the bottom layer of the deep segment. When the depth gradient is steep, any horizontal mixing that occurs in the model can act as vertical mixing, so that vertical stratification may be broken up by mixing more rapidly than actually occurs. More than 90 percent of the models that HydroQual develops use sigma-layer coordinates.

Model input was collected from a number of sources. Meteorological information was obtained from the JFK Airport. Tide elevations and salinity and temperature boundary conditions were obtained from the Jamaica Bay Eutrophication Model (JEM), which was run for the year 2002 rainfall conditions.

RCA (Row-Column AESOP) was used for the water quality model. Eutrophication kinetics with 25 state-variables were used for this analysis. The kinetics are similar to those used for the Jamaica Bay Eutrophication Model (JEM) (HydroQual, 2002). The water quality

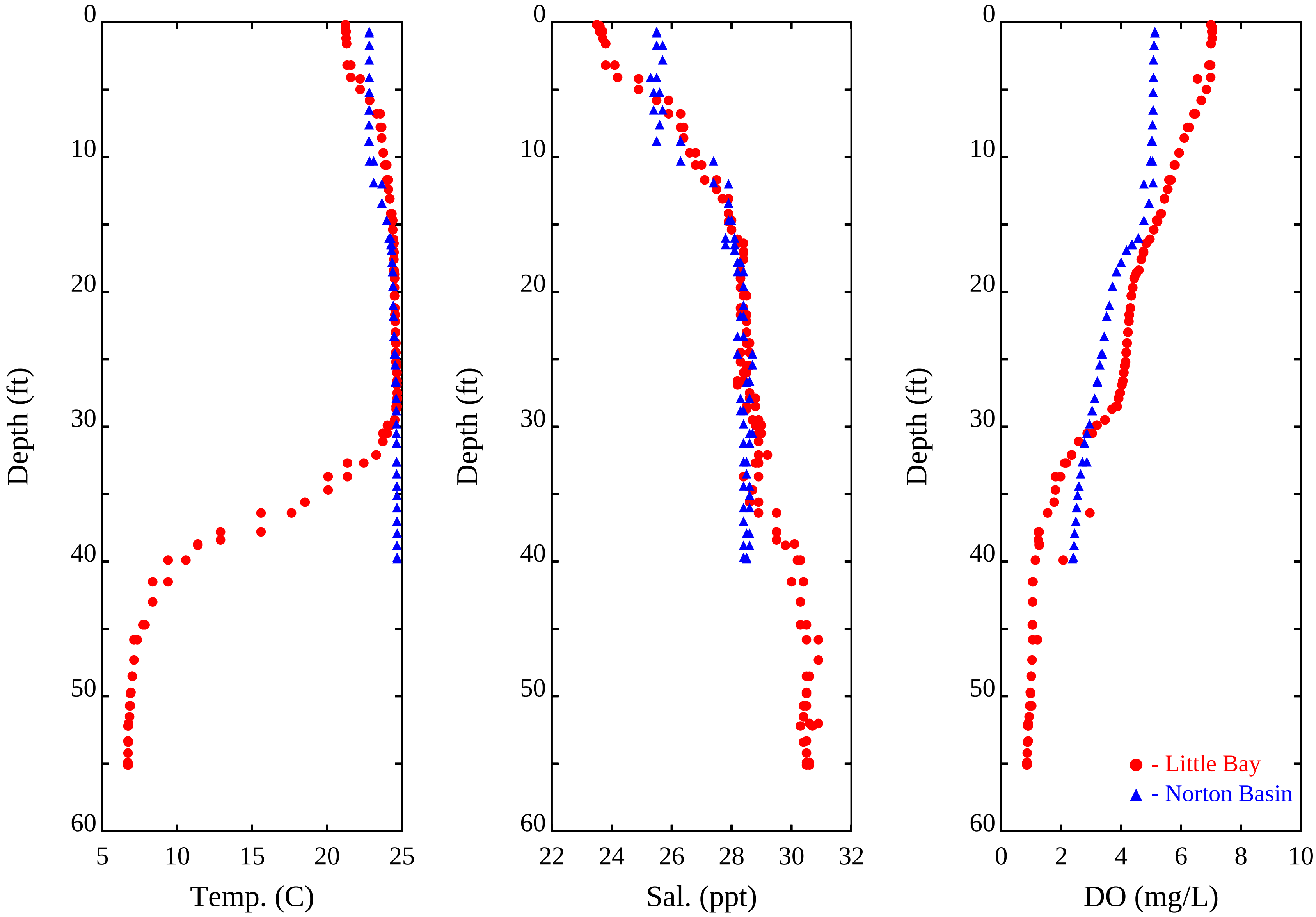



Figure 2-2. Vertical Profile Data - August, 2002

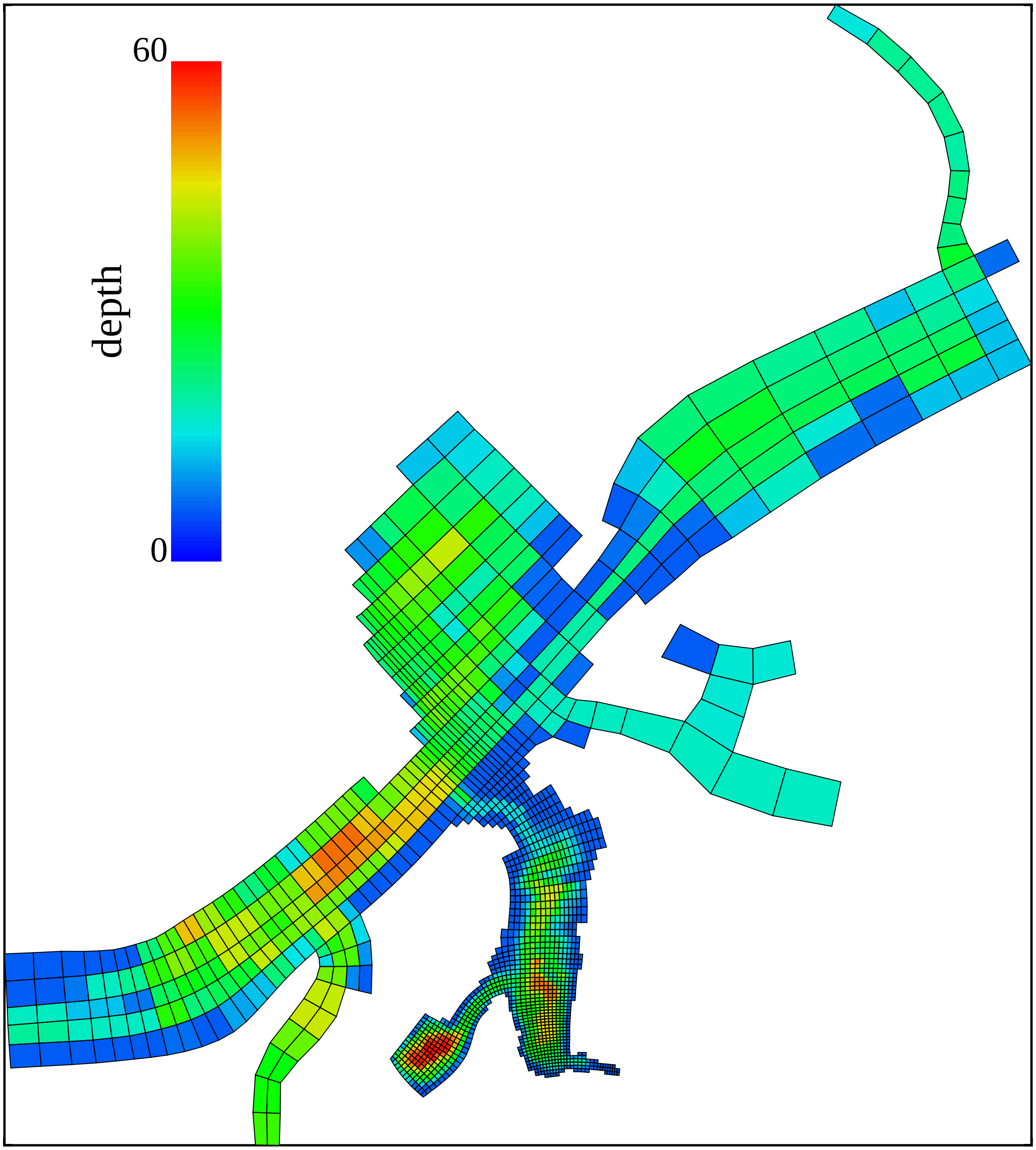



Figure 2-3. Original Norton Basin/Little Bay Model Segmentation

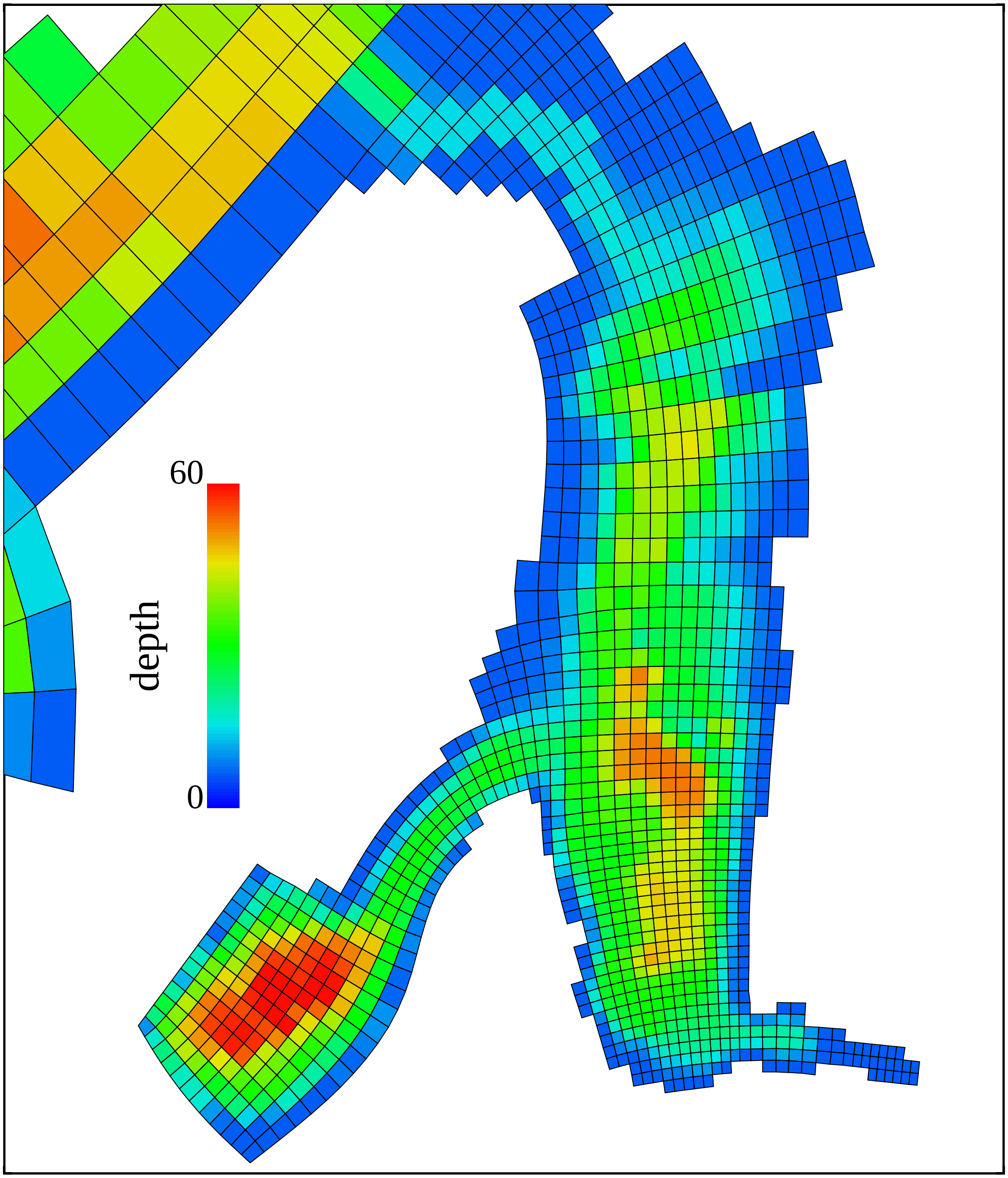



Figure 2-4. Close Up of Original Norton Basin/Little Bay Model Segmentation

model requires loading information. Loadings to this portion of Jamaica Bay include combined sewer overflows (CSOs), storm sewers, the Cedarhurst wastewater treatment plant, the Edgemere Landfill, and atmospheric deposition. Another large source is the boundary in Beach Channel where nutrients from the four major NYC water pollution control plants can enter the model domain. In the first round of modeling the Cedarhurst WWTP and the Edgemere Landfill source were omitted due to time constraints. The largest sources were the CSOs and storm sewers in the area. Flow estimates from these sources were obtained from the RAINMAN model, which is a simple rainfall runoff model developed for NYCDEP. Concentrations were based on data collected within the Jamaica Bay drainage area as part of the Jamaica Bay Eutrophication Study (JES). Concentrations used for atmospheric deposition were also based on data collected during JES. Boundary conditions were developed using output from a JEM run for 2002 conditions.

The model was set up and run for 2002 conditions. Preliminary results were promising, but the hydrodynamic model was unable to reproduce the temperature stratification that was measured in Little Bay. This was primarily due to the upslope mixing problem discussed earlier. The preliminary results were presented to the USACE and PANYNJ on November 16, 2005.

Phase 2: Development of Hydrodynamic/Water Quality Model.

Phase 2 of the project was conducted with funding from the NYCDEP. The tasks included:

a. Complete the hydrodynamic/water quality model calibration.
b. Conduct up to 10 recontouring modeling scenarios.
c. Prepare a modeling report.

After considerable effort was made to calibrate the sigma-layer hydrodynamic model, the sigma-layer model was abandoned because of the model's inability to reproduce the temperature stratification observed in Little Bay. The hydrodynamic model was reconfigured to a Z-level coordinate system. In this configuration, the number of vertical layers is determined by the depth of the segment. A two-meter interval was chosen for the vertical layers. The deepest area, in Little Bay, still has 10 vertical layers, and the shallower areas have only one two-meter vertical layer. The Z-level model also allowed for coarser resolution. This resulted in reducing model run times from approximately three days to less than a half a day. The updated Z-level model grid is presented in Figure 2-5. Model inputs were adjusted to the new configuration, and the Cedarhurst WWTP and Edgemere Landfill loads were added to the model.

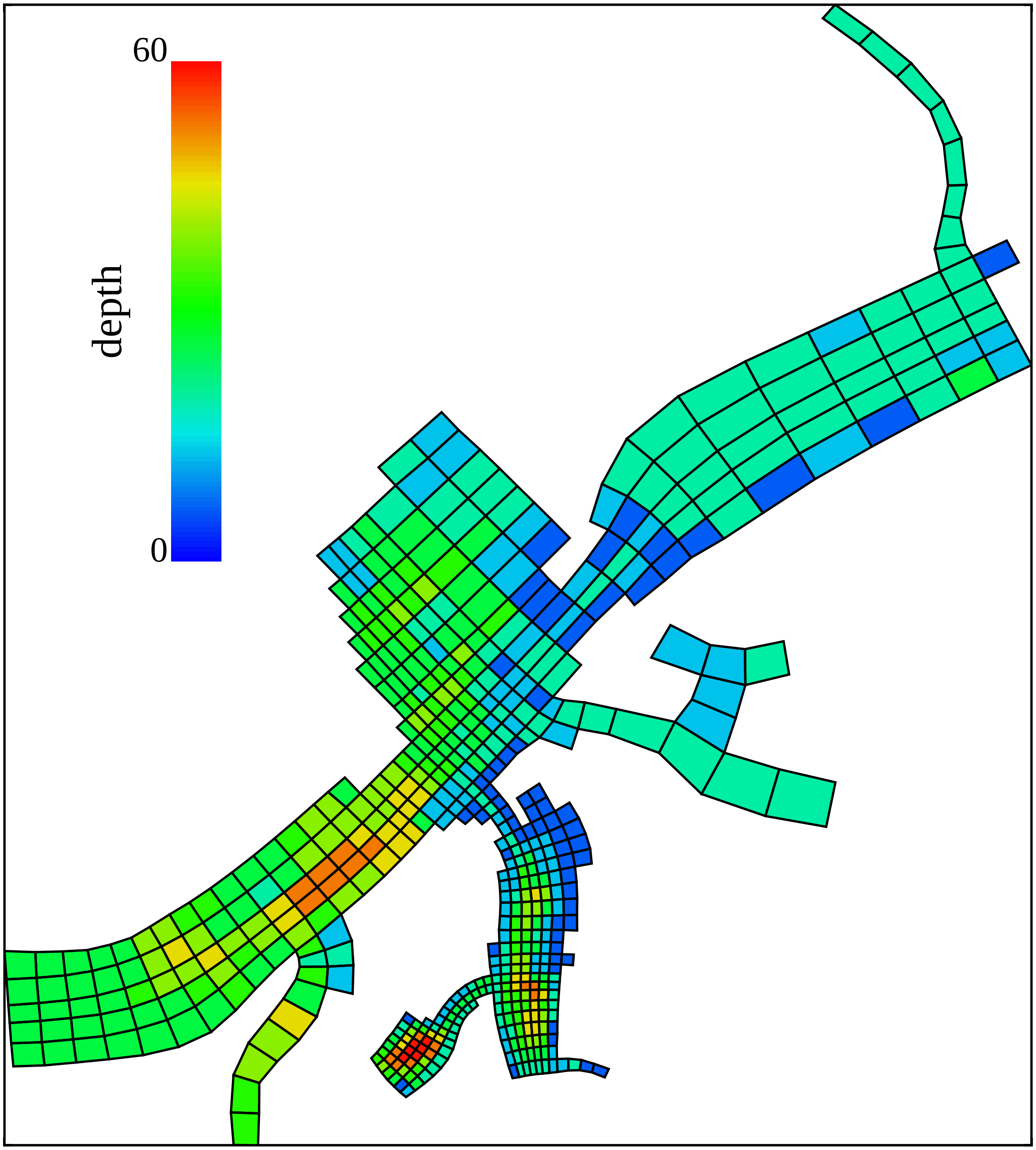



Figure 2-5. Final Norton Basin/Little Bay Model Segmentation

The most challenging portion of the modeling analysis was reproducing the temperature stratification observed in Norton Basin and Little Bay. The heat flux model was able to reproduce the surface temperatures quite well. However, the bottom temperatures were more of a challenge. Norton Basin, at a depth of approximately 50 feet is relatively well mixed with surface to bottom temperature stratification of 2-4 °C during portions of the year. In Little Bay, much more significant temperature stratification is observed. At approximately, 65 ft. in depth, bottom water temperatures remain at or below 7 °C during the entire year, while surface temperatures reach 25 °C during the summer. A strong pycnocline is observed at approximately 30-40 ft. in depth, a depth shallower than Norton Basin. During the cooler months, no temperature stratification is observed in either basin.

Many attempts were made to reproduce the temperature differences between the two basins including modifications to the bathymetry, winds, and penetration of solar radiation. Only with the introduction of the mixing effects of groundwater was the temperature distribution in Norton Basin reproduced. The groundwater table slopes toward Norton Basin from the east. More land area is available on the eastern side of Norton Basin than the western side of Little Bay. The greater land area on the eastern side results in more groundwater flow to Norton Basin than to Little Bay, and can explain the differences observed in the vertical temperature stratification. There is anecdotal evidence that groundwater can be seen percolating from the shoreline of Norton Basin during low tide. This observation provides credence to the hypothesis that groundwater is a factor in the vertical mixing of Norton Basin. The groundwater flow is estimated to be approximately 0.5 to 1.0 MGD. This flowrate is large enough to induce mixing, but small enough to have an almost unnoticeable impact on the salinity in the basin.

Figure 2-6 presents the results of the temperature calibration at six locations within the model domain. Sampling stations tended to vary slightly from survey to survey making model to data comparisons somewhat challenging. The stations shown on the map and listed first above each panel were sampled by Continental Shelf Associates, Inc. as part of the Barry A. Vittor & Associates, Inc. sampling program. If data from a nearby NYSDEC sampling location were available, these data are presented as well. The NYSDEC sampling station name is presented as the second station name above each panel. At LBPit1, NBPit1, and NBPit3, Pit is abbreviate as P on the location map. In Grass Hassock Channel, at station GHC1, the data, represented by the symbols in the figure legend, indicate there is little if any temperature stratification between the surface and bottom. The model reproduces the well-mixed conditions. The data collected in the entrance channel to Norton Basin, at stations NBEC1 and NEB1, also show very little temperature stratification. The model generally reproduces the data calculating small differences between the surface and bottom temperature during the spring. Data in the entrance to Little Bay (stations LBEC1

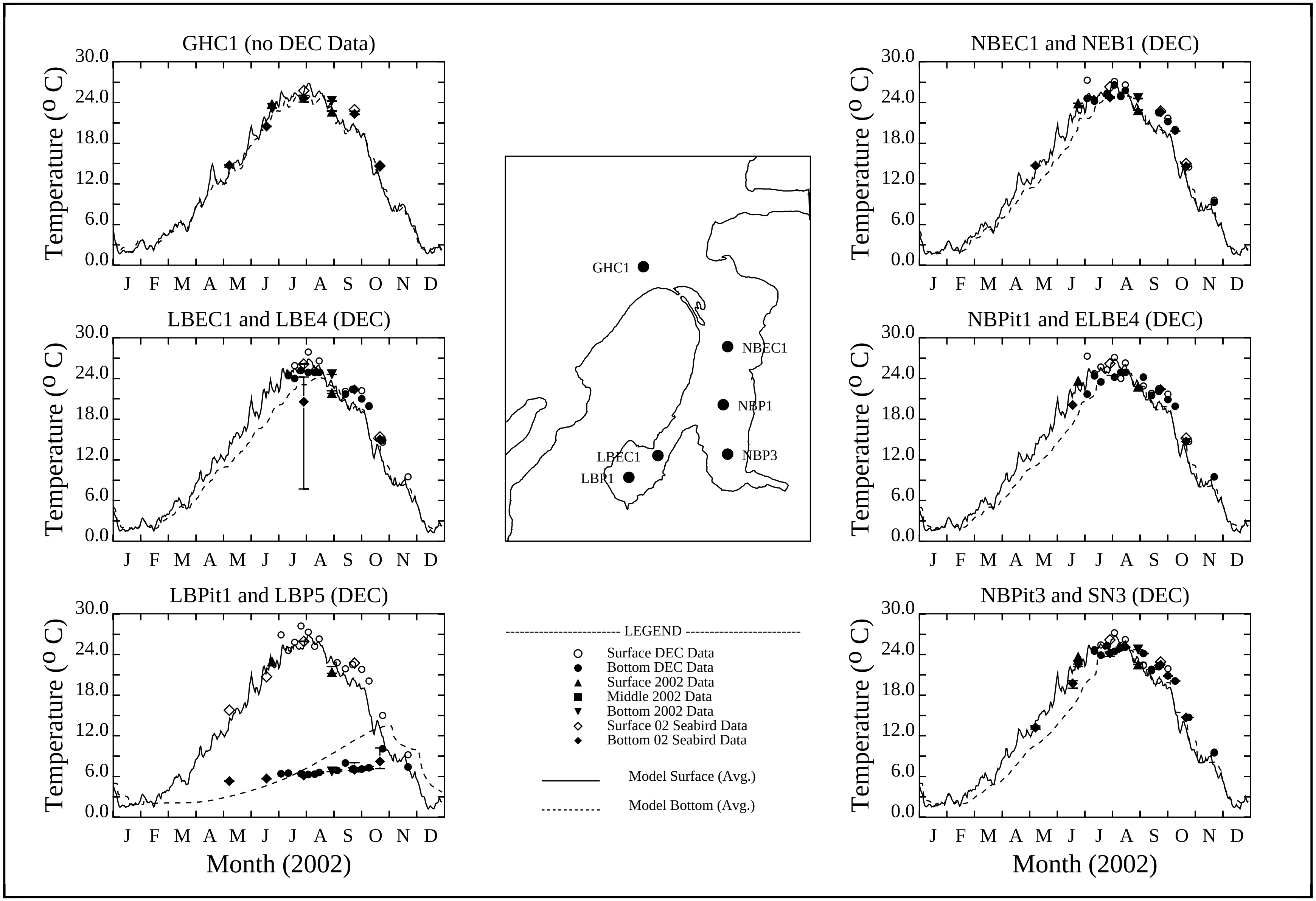



Figure 2-6. Time Series Comparison of Model Versus Data for Temperature

and LBE4) indicate there can be small differences between the surface and bottom temperature, and the model calculates more stratification in the entrance to Little Bay than the entrance to Norton Basin. Temperature data collected in the Norton Basin pits, at stations NBPit1/ELBE4 and NBPit3/SN3, indicate that the basin is vertically well mixed. The model reproduces the surface data quite well, but tends to under calculate the bottom temperatures by two to three degrees Celsius during the spring. The data collected in Little Bay, at stations LBPit1 and LBP5, show a distinct contrast to the data collected at the other stations. Bottom water temperatures remain below approximately 7 $^{o}$C during the year. The model is able to reproduce these temperatures fairly well, but begins to over estimate the bottom temperature during August and surface and bottom water temperatures are calculated to be the same during mid-October instead of late-November as the data indicate. Overall the temperature calibration can be considered quite good considering the differences in temperatures that are observed over a relatively small area.

The salinity calibration is presented in Figure 2-7. Boundary conditions for the hydrodynamic model were obtained by running JEM for 2002 conditions. Salinity data were sparse at the boundary of JEM, so a few iterations were required to develop reasonable boundary conditions for the Norton Basin/Little Bay Model. In general, the salinity data are similar from station to station except for the bottom data in the Little Bay pit. Most of the salinity data show well-mixed conditions. The model reproduces these conditions. Bottom data in Little Bay tend to be higher than other portions of the study area. The model calculates relatively unchanging conditions in the bottom of the Little Bay pit.

Loads for the model were developed by several methods. CSO and stormwater flows were obtained from a InfoWorks model of the area and 2002 rainfall data. CSO and stormwater concentrations were based on data collected from the WPCPs and storm sewers in the Jamaica Bay area. Loadings from the Cedarhurst WWTP were based on available plant records. Edgemere Landfill loads were based on estimated flows and available concentration data. Atmospheric loading was based on dry- and wet-fall data collected during the Jamaica Bay Eutrophication Study. Loads and concentrations used for this modeling effort are found in Tables 2-1 and 2-2. Loads remained the same in the projection scenarios.

Loadings into the model domain are relatively small compared with other sections of Jamaica Bay. Within the model domain, nitrogen and phosphorus loads are almost equally divided between CSOs, storm sewers, and the Nassau County operated Cedarhurst wastewater treatment plant (Figure 2-8). Carbon loads are dominated by the CSOs and stormsewers. The Edgemere Landfill is no longer in operation and has been capped, so the pollutant load from this source is small. Atmospheric deposition over this small area is also quite small. Sources outside the model domain have probably the largest impact on

**Table 2-1. Model Loads (lbs/day)**

| | TP | TN | DIN | TOC | BOD |
|---|---|---|---|---|---|
| Norton Basin (SW, Landfill) | 1.8 | 36.4 | 24.3 | 151.5 | 87.8 |
| Little Bay (SW, Landfill) | 0.4 | 26.0 | 20.4 | 68.9 | 43.0 |
| Landfill – Entire Domain | 0.0 | 68.3 | 57.4 | 129.2 | 86.8 |
| CSO | 26.7 | 206.0 | 77.3 | 1631.7 | 885.7 |
| SW – Entire Domain | 26.7 | 206.0 | 77.2 | 1632.9 | 885.6 |
| WPCP | 26.9 | 178.0 | 127.6 | 157.2 | 165.0 |
| Atmospheric Loads | 0.1 | 2.9 | 1.4 | 3.6 | - |
| Total Loads | **80.4** | **661.1** | **341.0** | **3554.7** | **2023.2** |

**Table 2-2. Model Concentrations (mg/L)**

| | Storm water | CSO (Sanitary portion) |
|---|---|---|
| Organic Phosphorus | 0.16 | 1.1 |
| Phosphate ($PO_4$) | 0.11 | 2.4 |
| Organic Nitrogen | 1.30 | 12.5 |
| Ammonia ($NH_4$) | 0.27 | 19.2 |
| Nitrate and Nitrite ($NO_2$ + $NO_3$) | 0.51 | 0.28 |
| Dissolved Silica (DSi) | 1.45 | 10 |
| Organic Carbon | 16.50 | 83.4 |
| BOD | 9.00 | 151 |
| DO | 6.30 | 1.0 |

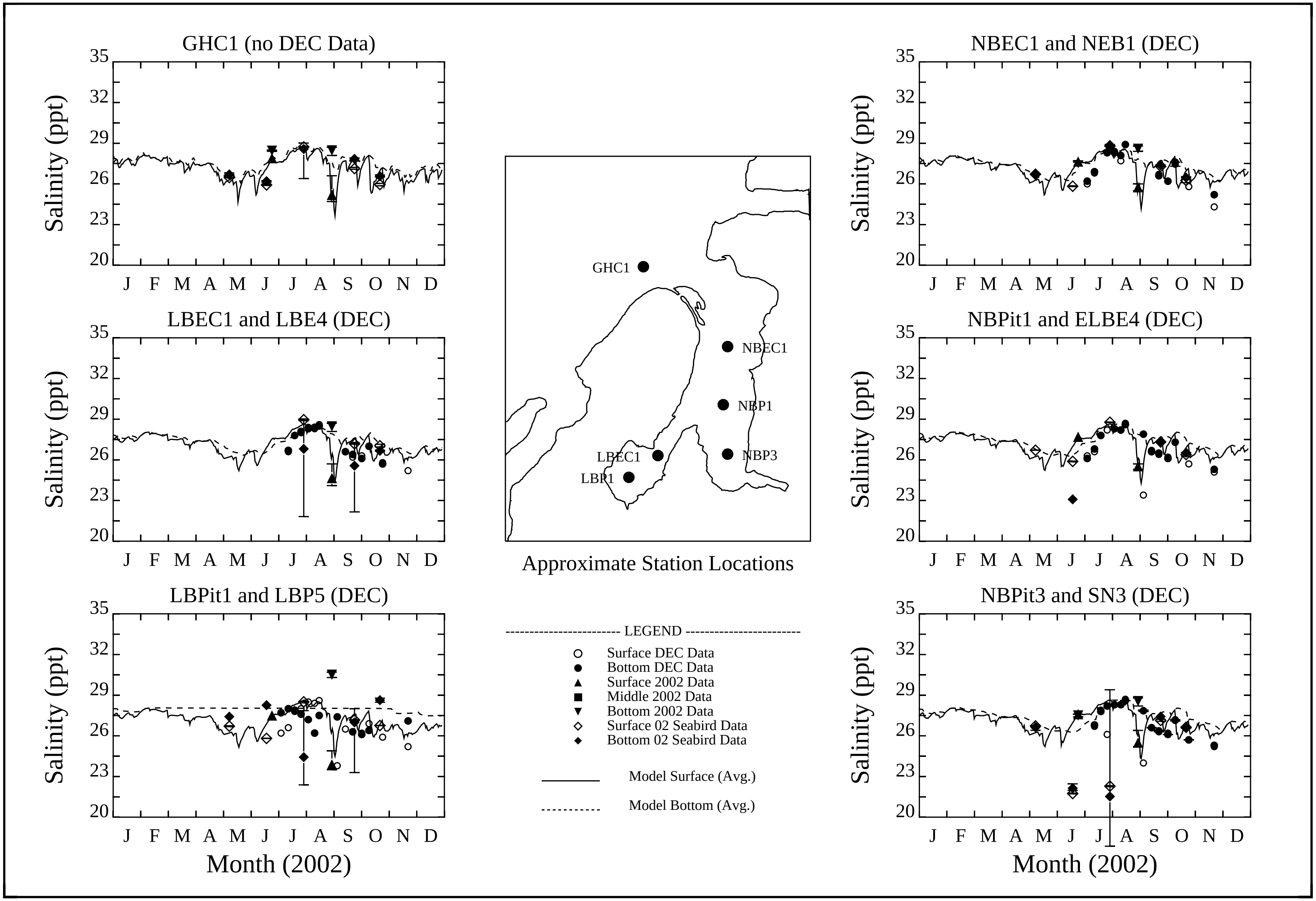



Figure 2-7. Time Series Comparison of Model Versus Data for Salinity

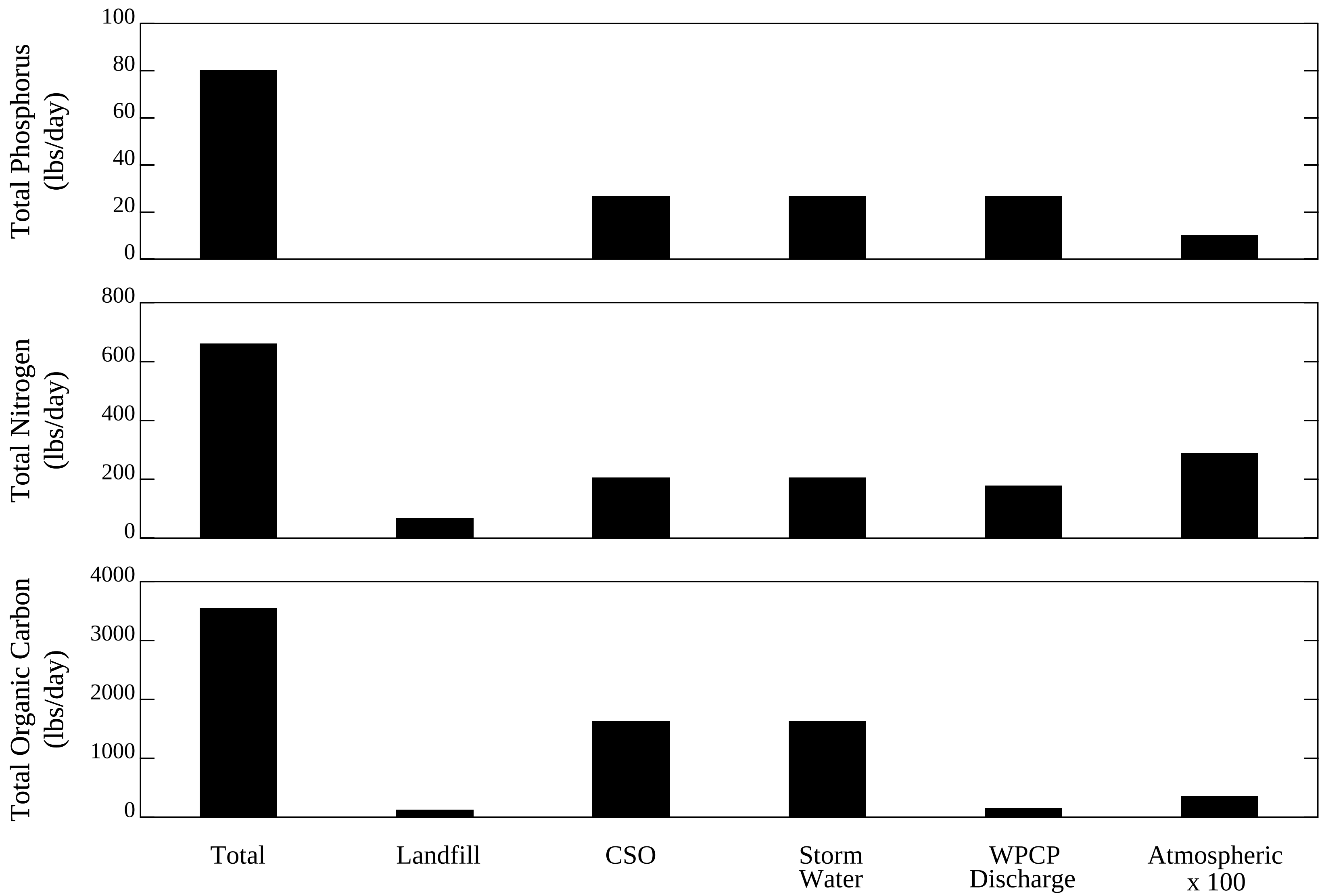



Figure 2-8. Loading Distribution by Source

pollutant concentrations in the model as they enter through the assigned boundary conditions via tidal currents.

Figure 2-9 presents a comparison of the loads discharged into the model domain to the discharges into Norton Basin and Little Bay. From this figure it is apparent that it is thecombination of outside loadings and basins' bathymetry that result in the poor water quality in the basins. The average total nitrogen loading to the model domain is a little more than 600 lb/day. For comparison, the total nitrogen loading into Jamaica Bay from the four New York City WPCPs is between 35,000 and 40,000 lb/day. Improvements in water quality in Norton Basin and Little Bay will not result from reducing direct loads into these basins.

Boundary conditions were developed using the Jamaica Bay Eutrophication Model (JEM) that was developed as part of the Jamaica Bay Eutrophication Study (JES). Figures 2-10 through 2-12 present the boundary conditions used for the Norton Basin/Little Bay Model. Figure 2-10 shows the salinity, phytoplankton carbon and phosphorus boundary conditions. The salinity boundary conditions were obtained from the hydrodynamic model. The phytoplankton panels show that the winter diatoms dominate during the colder months while the summer assemblage dominates during the warmer months. Total phosphate, which is the sum of dissolved phosphate and the phosphate incorporated in the phytoplankton cells is the dominant phosphorus constituent. All of these state-variables show little difference between the surface and bottom concentrations.

Figure 2-11 presents the nitrogen and silica state-variables. The total ammonia and the dissolved components are the largest fractions of the total nitrogen concentration. It was believed that the nitrite + nitrate concentrations were underestimated by JEM during portions of the year, so the boundary concentrations were assigned a minimum of 0.1 mg/L. The majority of the silica entering the model domain is dissolved.

The final boundary condition figure is Figure 2-12. Figure 2-12 presents the organic carbon state-variables plus aqueous SOD (O2EQ, or the equivalent oxygen demand of hydrogen sulfide) and dissolved oxygen. Dissolved organic carbon is the largest component of the total carbon concentrations. Dissolved oxygen concentrations range from approximately 14 mg/L during the winter to approximately 5 mg/L during the late spring. The surface and bottom concentrations are similar.

Model calibration began with the model coefficients used for JEM. These coefficients seemed to work reasonably well for Norton Basin and Little Bay as well. The only modifications that were made had to do with the settling of algae and their incorporation into the sediment. In areas that are shallow, and known to be sandy, only a fraction of the organic matter that reached the sediment was allowed to be incorporated into

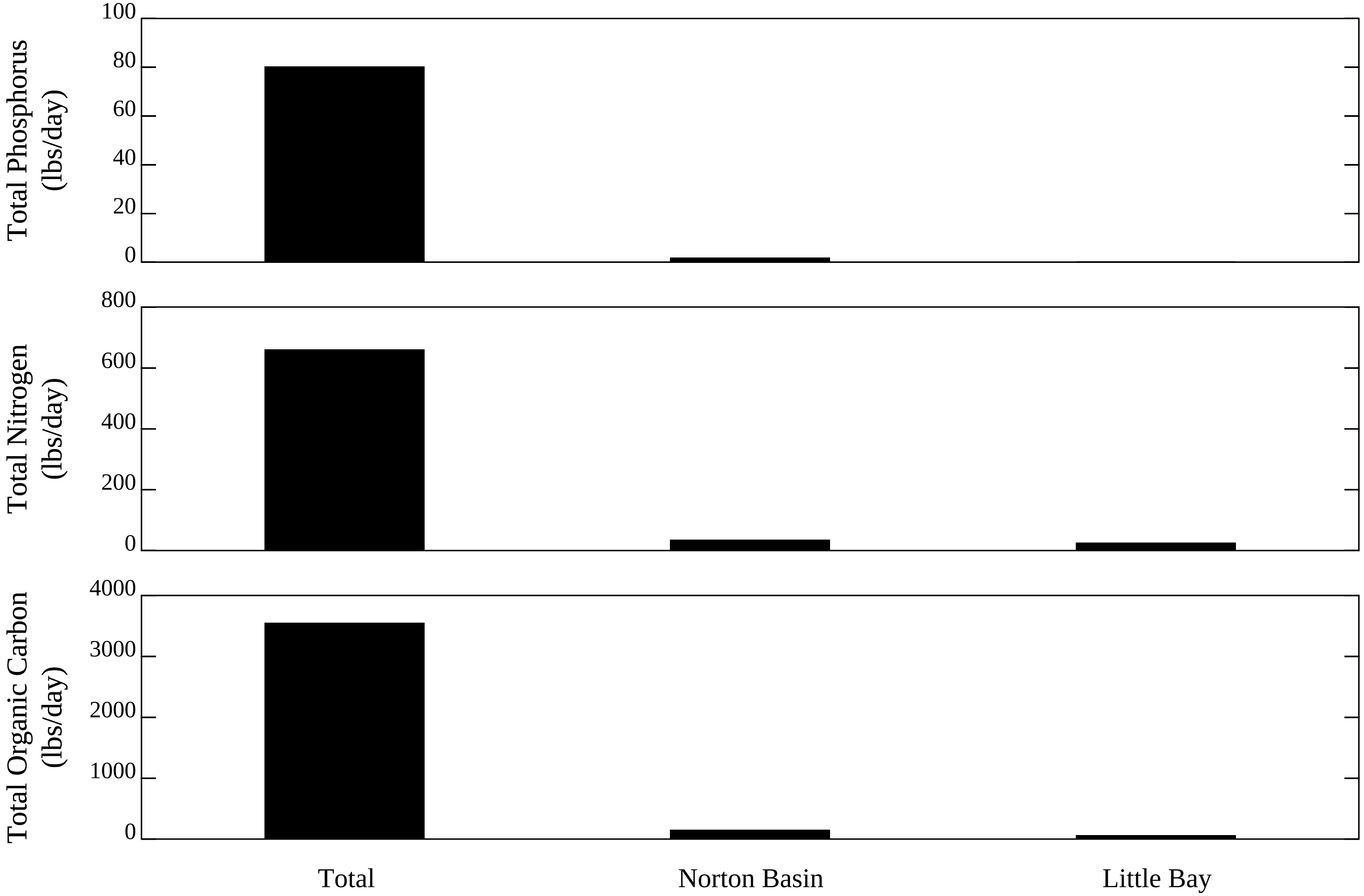



Figure 2-9. Loading Distribution by Location

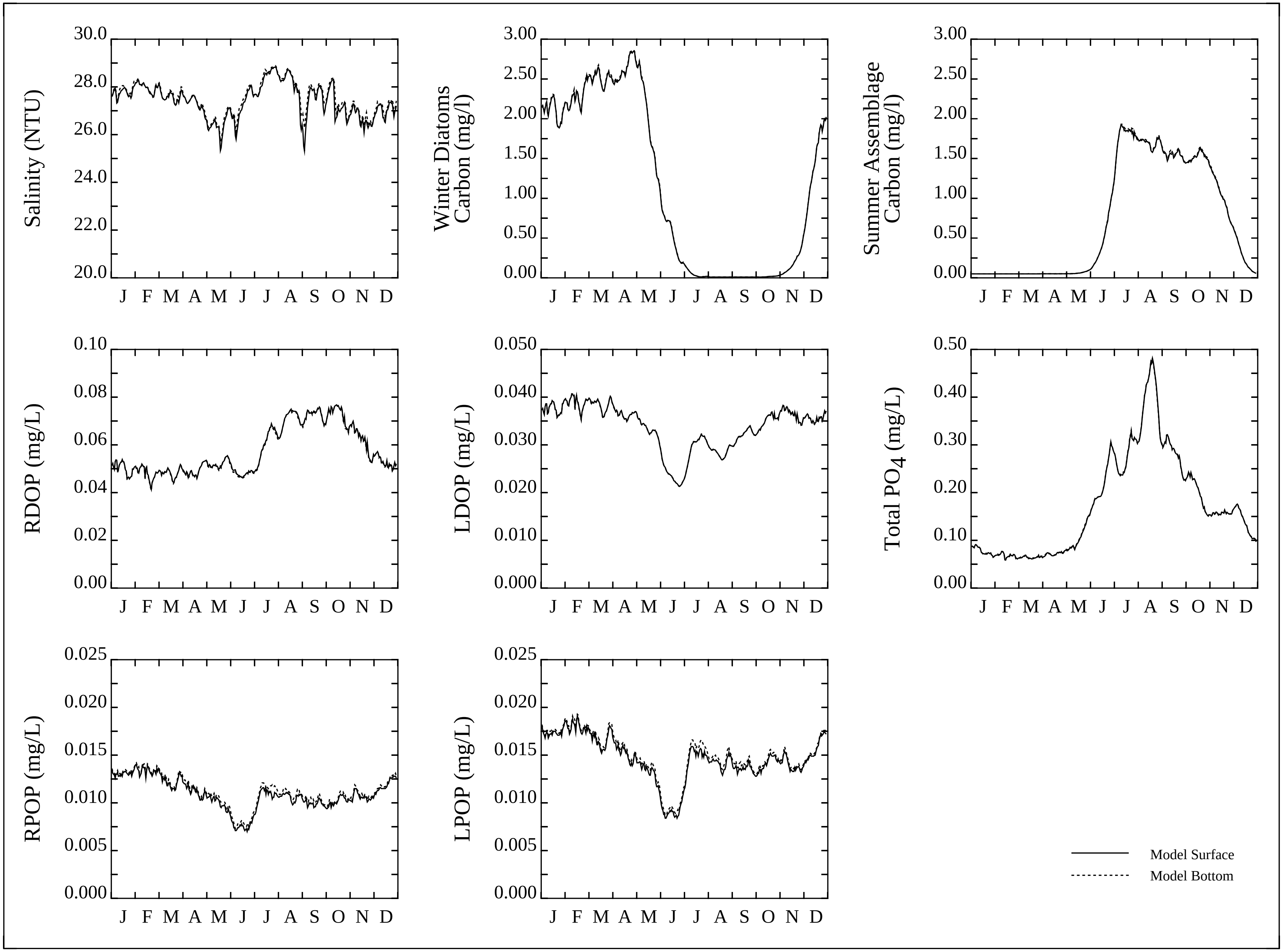



Figure 2-10. 2002 Boundary Conditions, Part 1

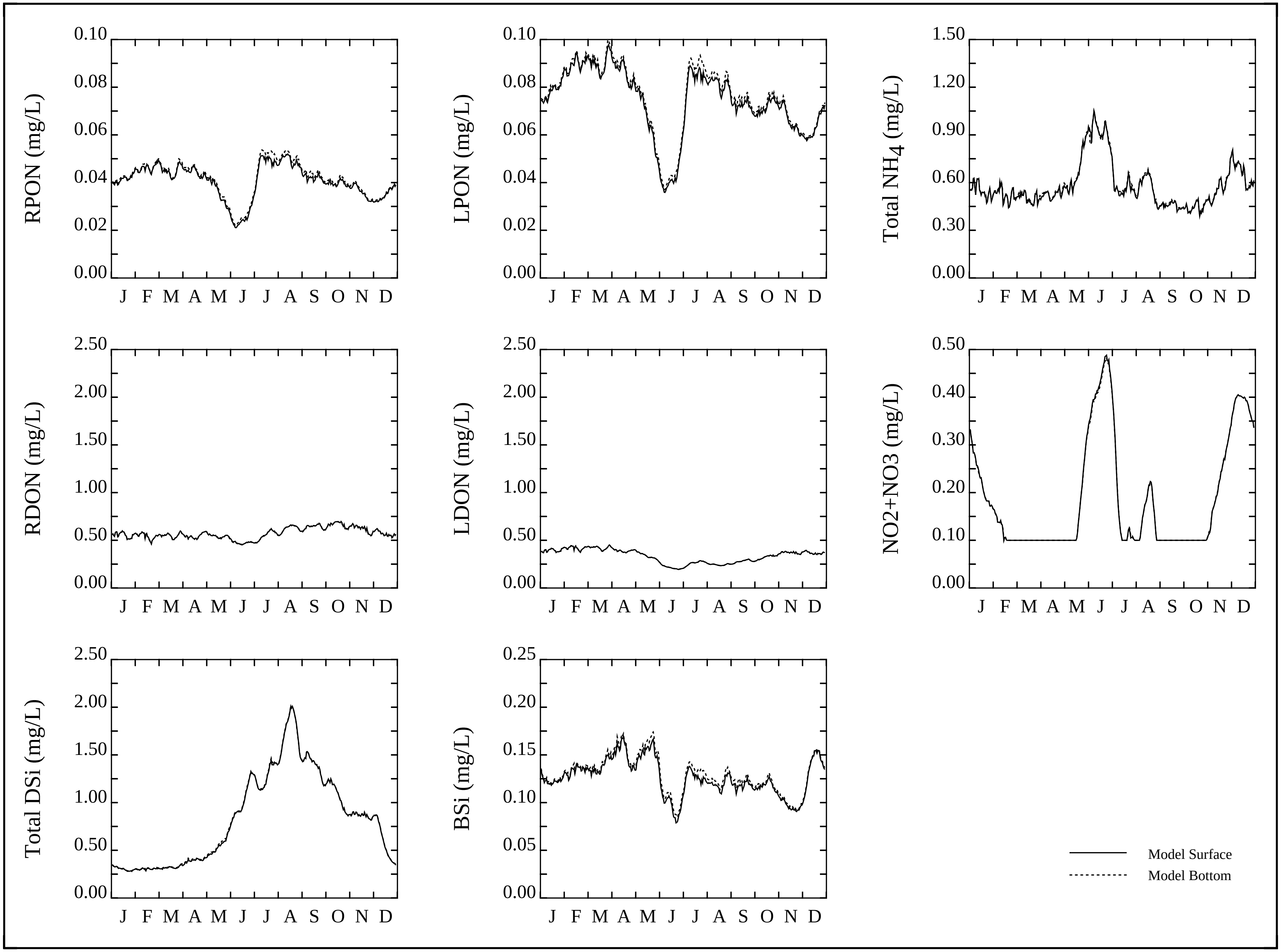



Figure 2-11. 2002 Boundary Conditions, Part 2

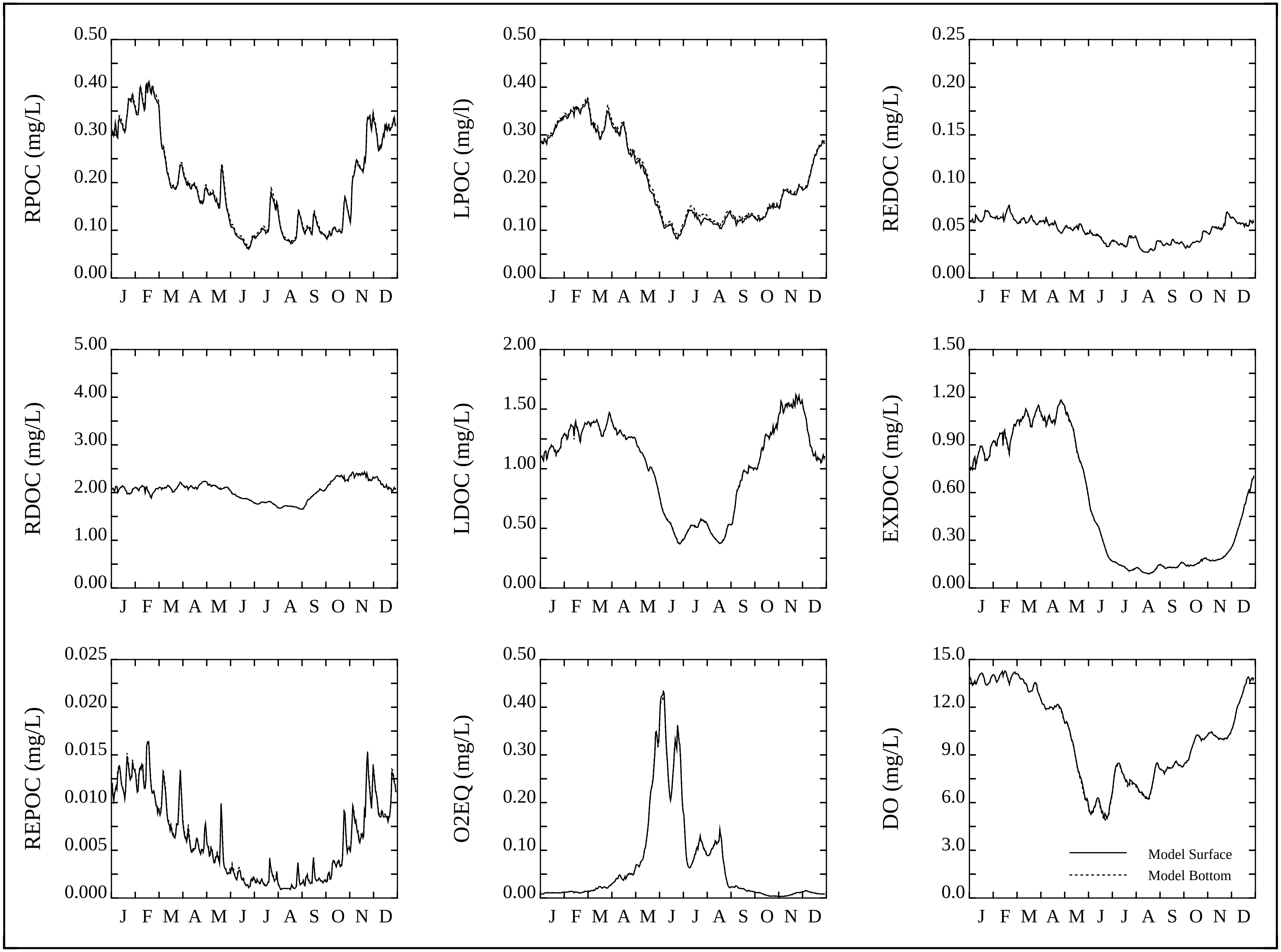



Figure 2-12. 2002 Boundary Conditions, Part 3

the sediment. This organic matter was required to travel into a deeper segment before it was allowed to be incorporated into the sediment. By this method, the resuspension of organic material in shallow areas was simulated.

Figure 2-13 presents the model versus data comparison for chlorophyll-a (Chl-a). Chl-a is an indicator of algal biomass. The highest measured chl-a occurred during early May and the model reproduces these high values. Summer chl-a concentrations were measured to be less than 20 ug/L. In the northern portion of the model domain, the mode reproduces the summer data. In the Norton Basin pit, the model calculates concentrations near the middle of the data. In Little Bay, the model underestimates the surface data and overestimates the bottom and mid-depth data. Overall, the model favorably reproduces the chl-a data.

Particulate organic carbon (POC) can be used as a separate indicator of algal biomass from chlorophyll-a. The model estimates that the vast majority of POC in the water column is phytoplankton. Figure 2-14 presents the model versus data comparison for POC. In general, the model approximates the POC data very well with only a few occasions where the model and data do not agree. The model calculates the highest POC concentrations in the earliest months of the year, and the lowest during June.

Model versus data comparisons for particulate organic nitrogen (PON) and particulate organic phosphorus (POP) are presented in Figures 2-15 and 2-16, respectively. The model tends to calculate the approximate magnitude of the data or over predict the data. Perhaps increasing the carbon to nitrogen and carbon to phosphorus ratios would have improved the model calibration, but the decision was made to use model coefficients that were used for JEM.

Figure 2-17 presents the model versus data comparison for ammonia ($NH_3$). In Grass Hassock Channel, the model results are dominated by the boundary conditions from JEM. The model results are generally, good for June and August, but the model underestimates the fall $NH_3$ data. The model versus data results are more favorable in the entrance channel to Norton Basin. The model favorably reproduces the bottom data in the Norton Basin pits. While the model does not exactly reproduce the data in Little Bay, it reproduces the general trends that are different from the other portions of the model domain. The low dissolved oxygen in Little Bay leads to higher ammonia fluxes from the sediment to the water column. Since Little Bay mixes poorly, the ammonia concentration steadily increases as the sediment fluxes more ammonia into the water column. Only when the model calculates mixing between the surface and bottom waters does the ammonia concentration in the bottom water decline in the fall.

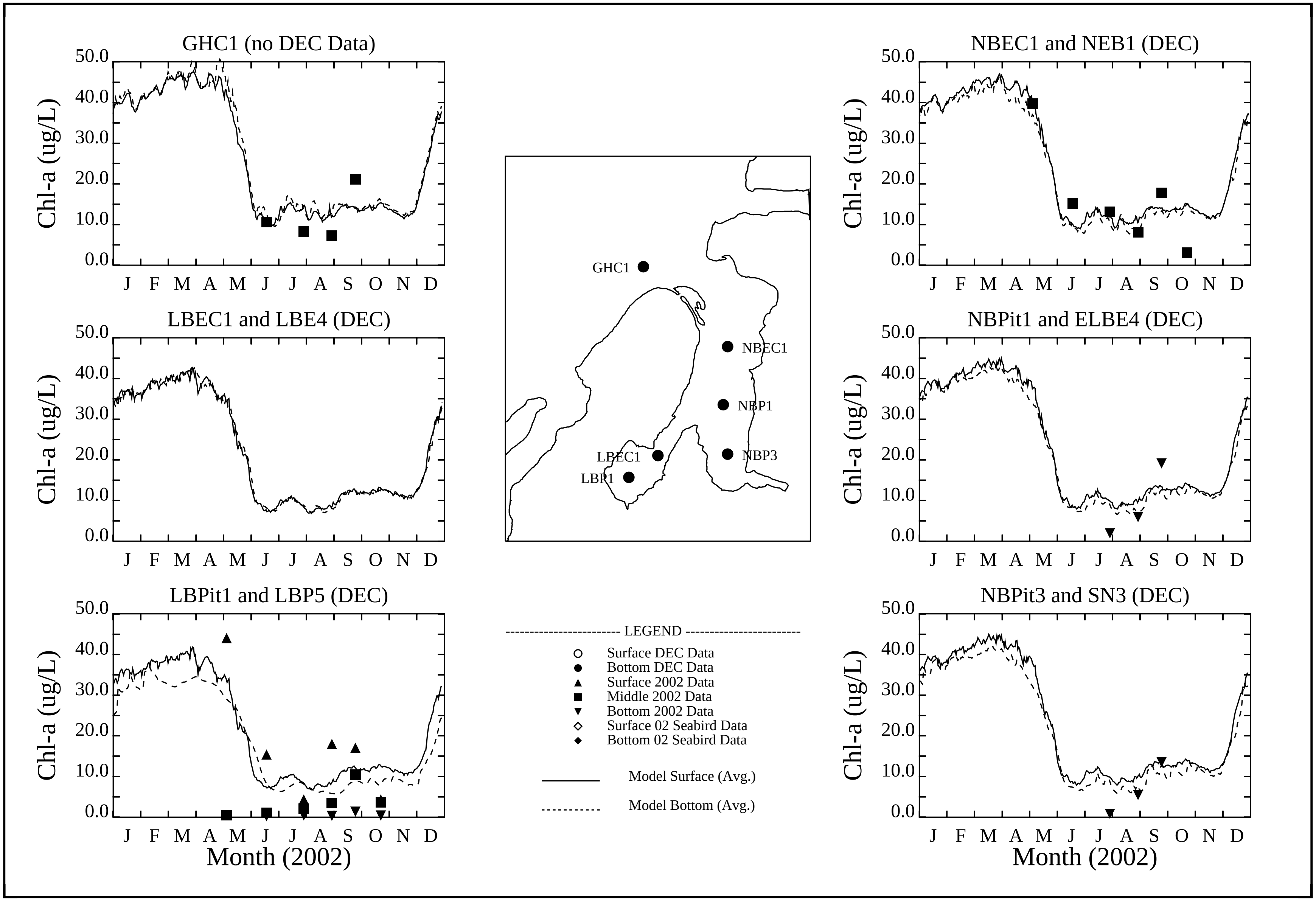



Figure 2-13. Time Series Comparison of Model Versus Data for Chlorophyll-a

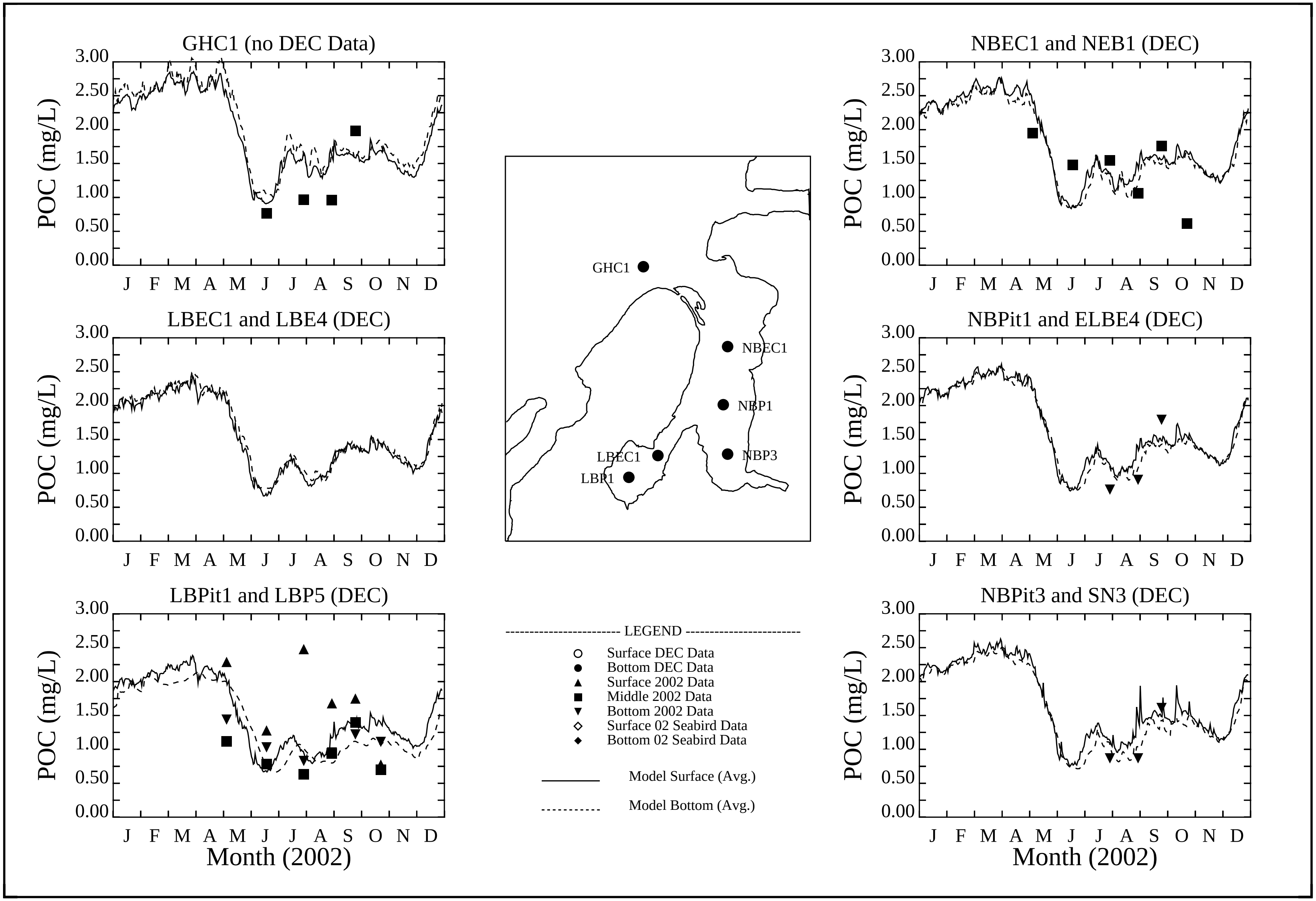



Figure 2-14. Time Series Comparison of Model Versus Data for Particulate Organic Carbon

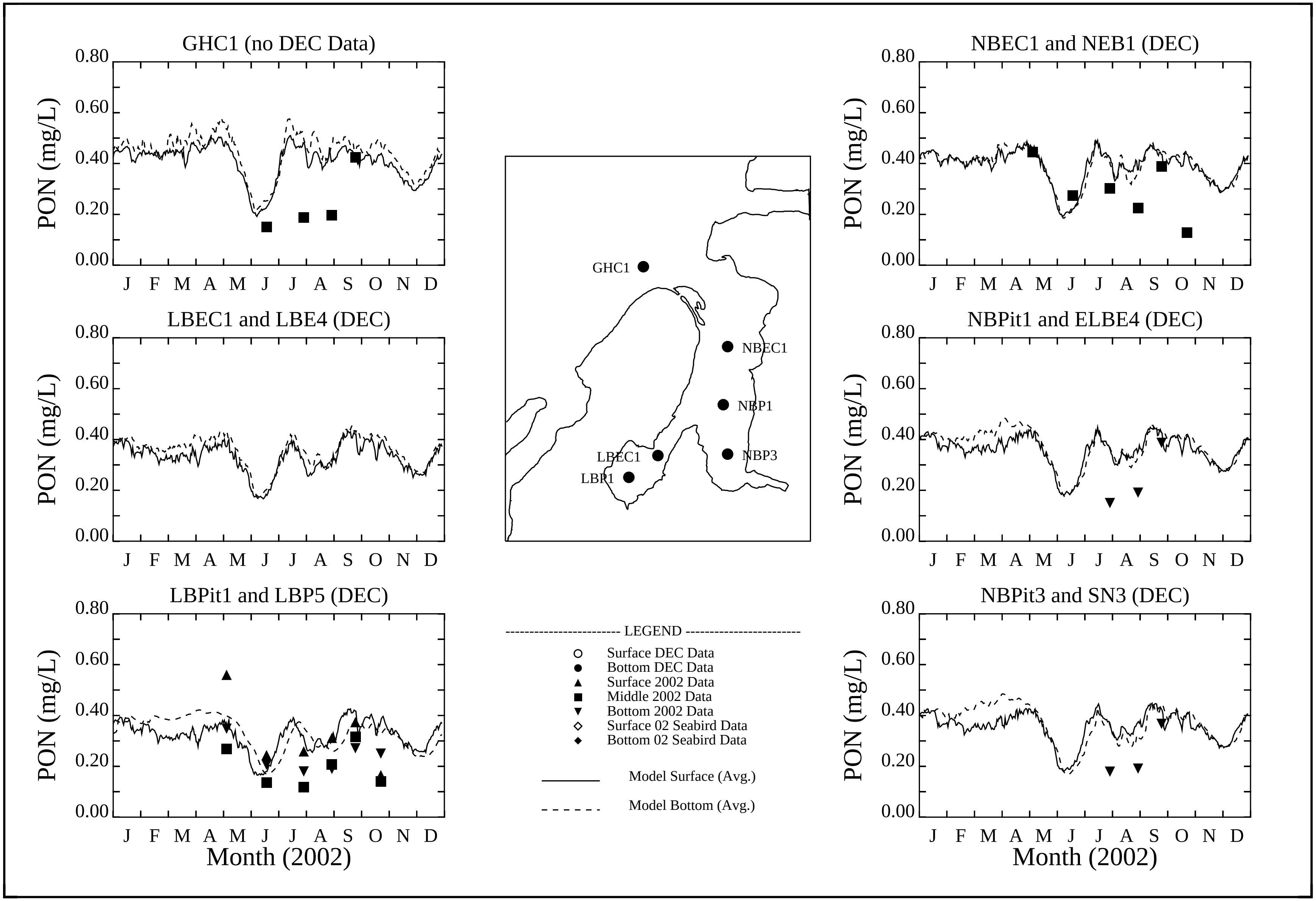



Figure 2-15. Time Series Comparison of Model Versus Data for Particulate Organic Nitrogen

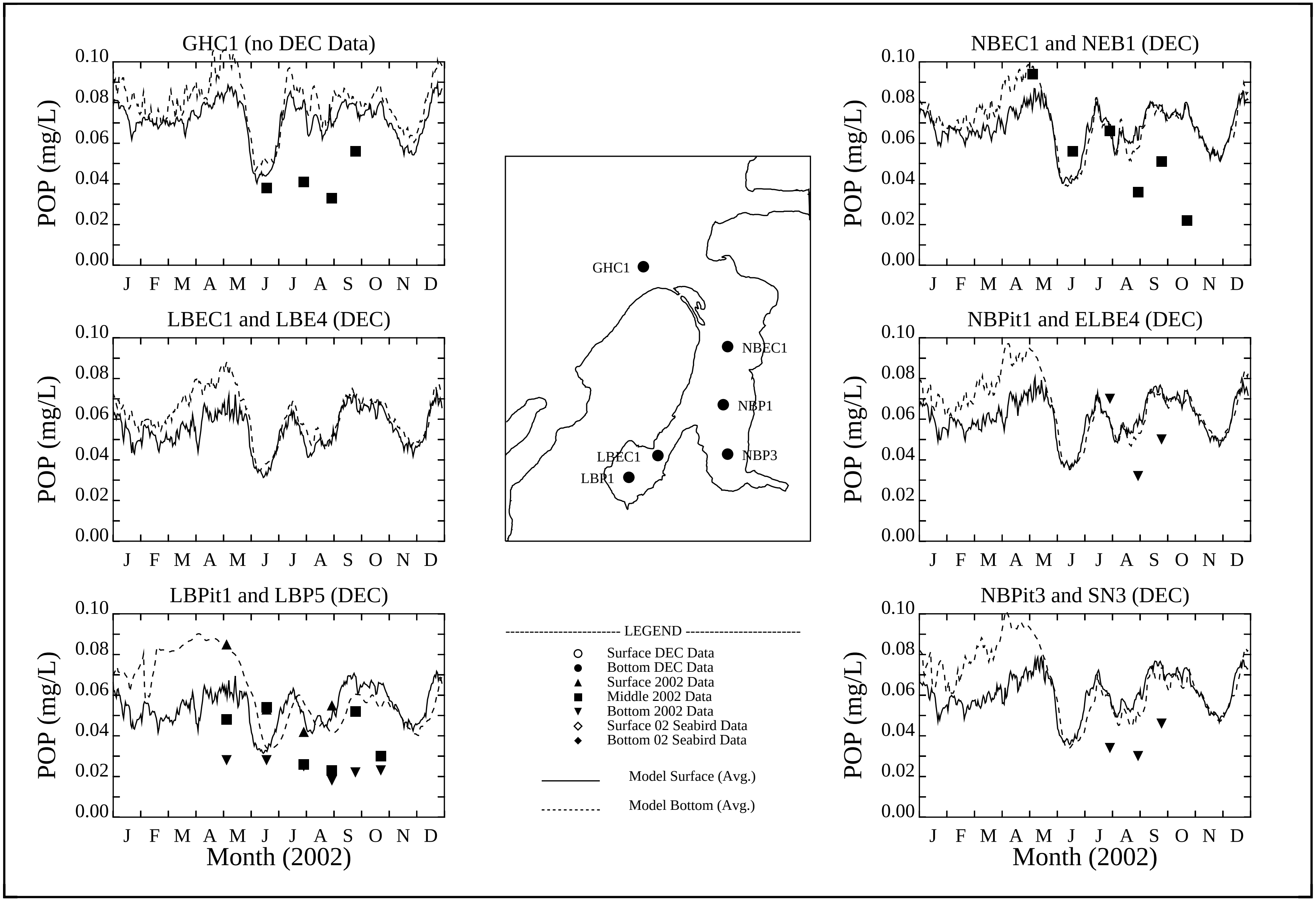



Figure 2-16. Time Series Comparison of Model Versus Data for Particulate Organic Phosphorus

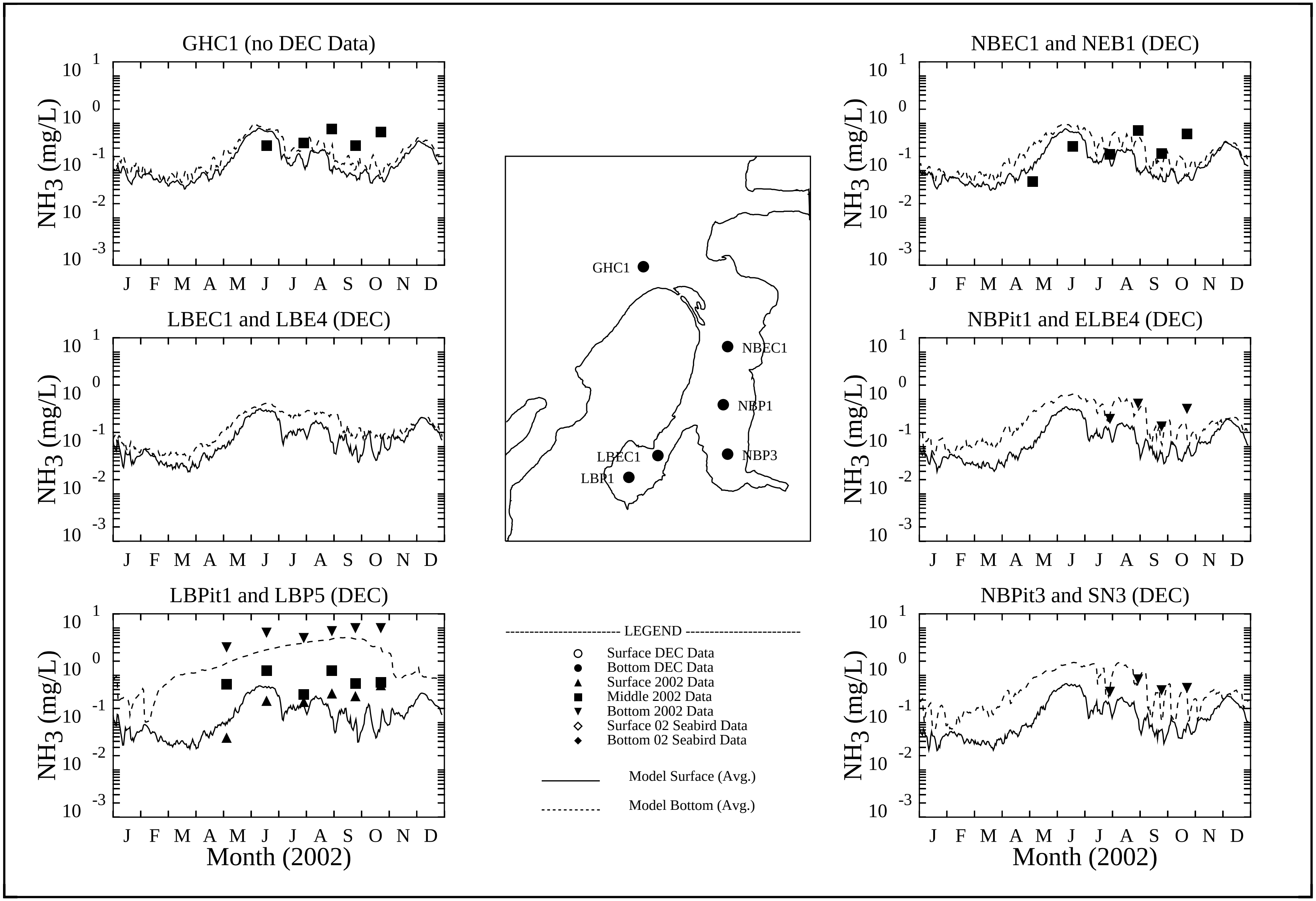



Figure 2-17. Time Series Comparison of Model Versus Data for Ammonia

The model comparison to the nitrite plus nitrate ($NO_2$+$NO_3$) data is not as favorable as the $NH_3$ calibration (Figure 2-18). The model line goes through some of the data, but misses other data points. One feature that the model partially reproduces is the lower $NO_2$+$NO_3$ concentrations in the bottom water versus the surface water in Little Bay. As the bottom water or the sediment becomes anoxic, nitrate is used as a source of oxygen. Denitrification reduces nitrite + nitrate levels in both the water column and sediment. A concentration gradient develops resulting in $NO_2$+$NO_3$ fluxing from the water column to the sediment, further reducing bottom water concentrations.

The model versus data comparison for total dissolved nitrogen (TDN) is presented in Figure 2-19. In most cases the model compares quite favorably to the data. The model reproduces the bottom TDN in Little Bay quite well. This brings into question some of the data that was collected. Since TDN should be the sum of the $NH_3$, $NO_2$+$NO_3$, and dissolved organic nitrogen, TDN concentrations should be higher than any of the individual components. In the case of $NH_3$, this does not hold true for the highest $NH_3$ concentrations. It is not clear whether the highest measured $NH_3$ concentrations are over estimated or the highest TDN concentrations are under estimated.

Dissolved inorganic phosphorus (DIP) results are presented in Figure 2-20. The model reproduces the DIP quite well at most stations. The model underestimates the DIP concentrations in the bottom of Little Bay, but does show that higher concentrations occur at the bottom of the pit than the surface waters. This results from phosphorus fluxes from the sediment into the water column. Total dissolved phosphorus (TDP) results, presented in Figure 2-21, are similar to the DIP results. The model reproduces most of the data except for the bottom data in Little Bay.

The model versus data comparison for dissolved silica (DSi), presented in Figure 2-22, is also quite good. The model reproduces the data at most stations quite well. As with some of the previous constituents, the model underestimates the DSi concentrations in the bottom waters of Little Bay. The model comparison with biogenic silica (BSi) is presented in Figure 2-23. In general, the model results are close to the measured concentrations, but the model tends to overestimate the observed data.

The final time series calibration figure is for dissolved oxygen (DO) in Figure 2-24. DO conditions vary considerably within the study domain. In Grass Hassock Channel the dissolved oxygen concentrations are similar at the surface and bottom. The model reproduces this feature. In the entrance channels to Norton Basin and Little Bay there is more vertical stratification than in Grass Hassock Channel. The model captures most of this stratification. Bottom DO concentrations appear to vary significantly over short periods of time, and the model reproduces a portion of these variations. In the Norton Basin pits the data show even more vertical DO stratification. Periods of anoxia are measured. The model

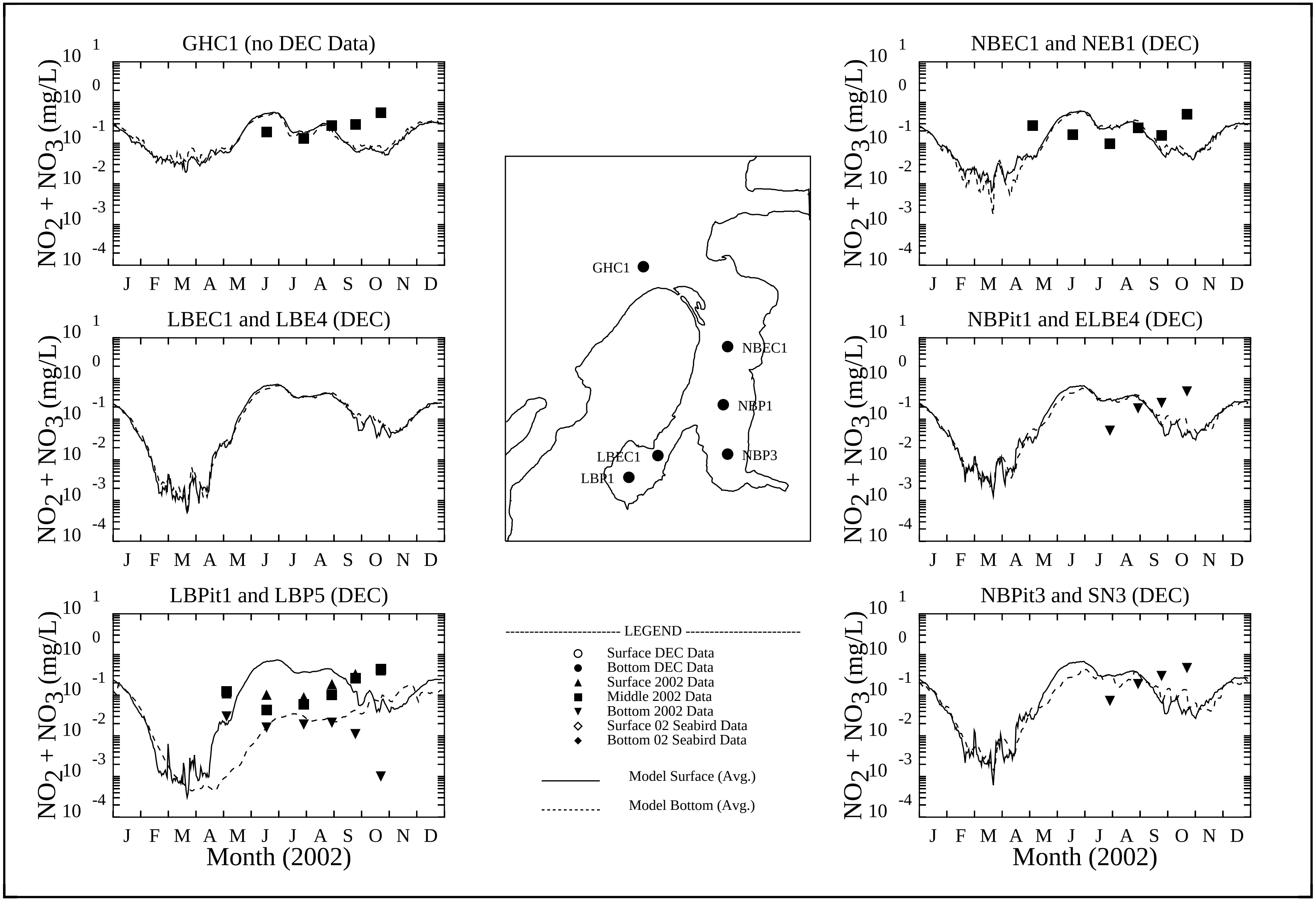



Figure 2-18. Time Series Comparison of Model Versus Data for Nitrite + Nitrate

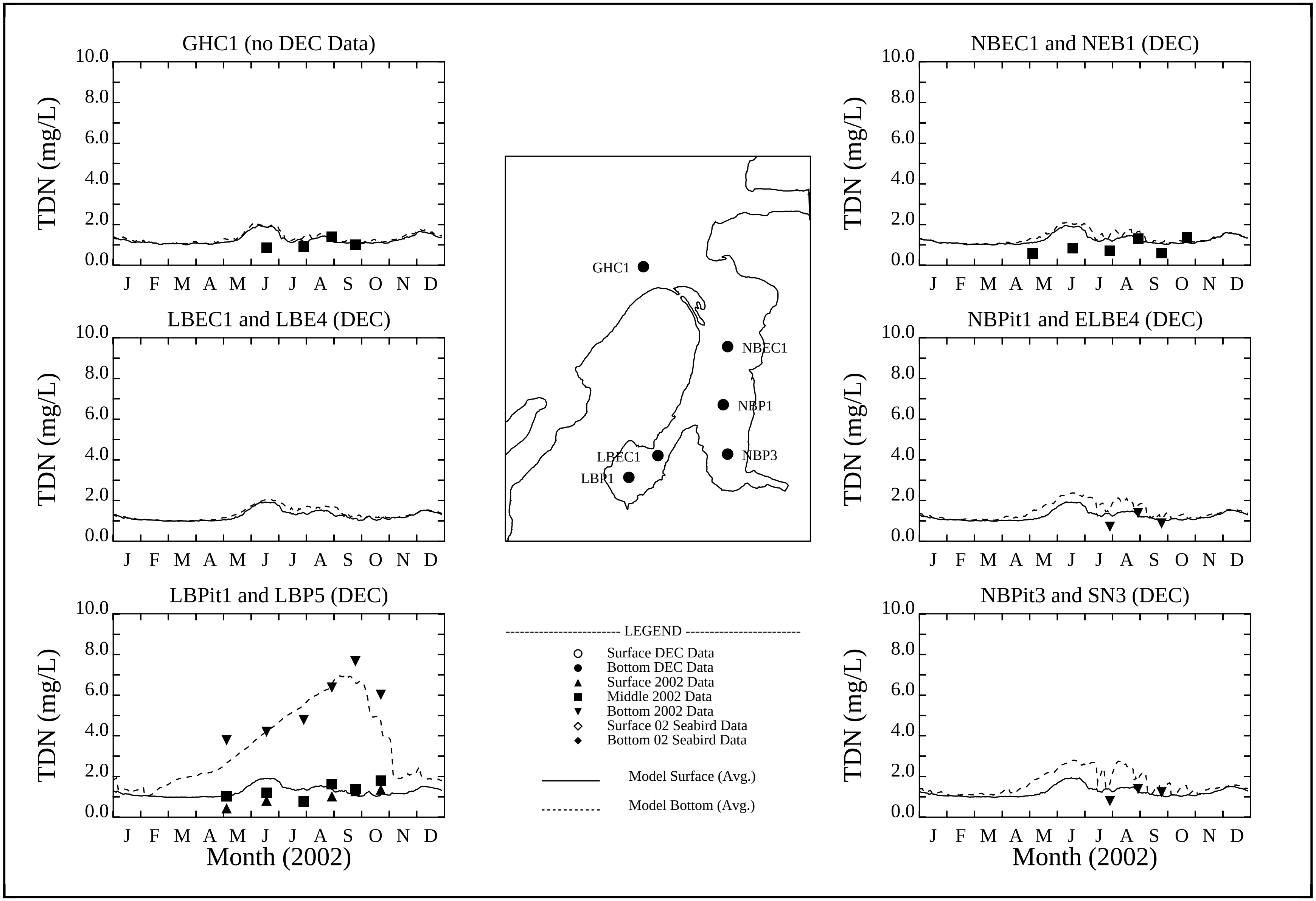



Figure 2-19. Time Series Comparison of Model Versus Data for Total Dissolved Nitrogen

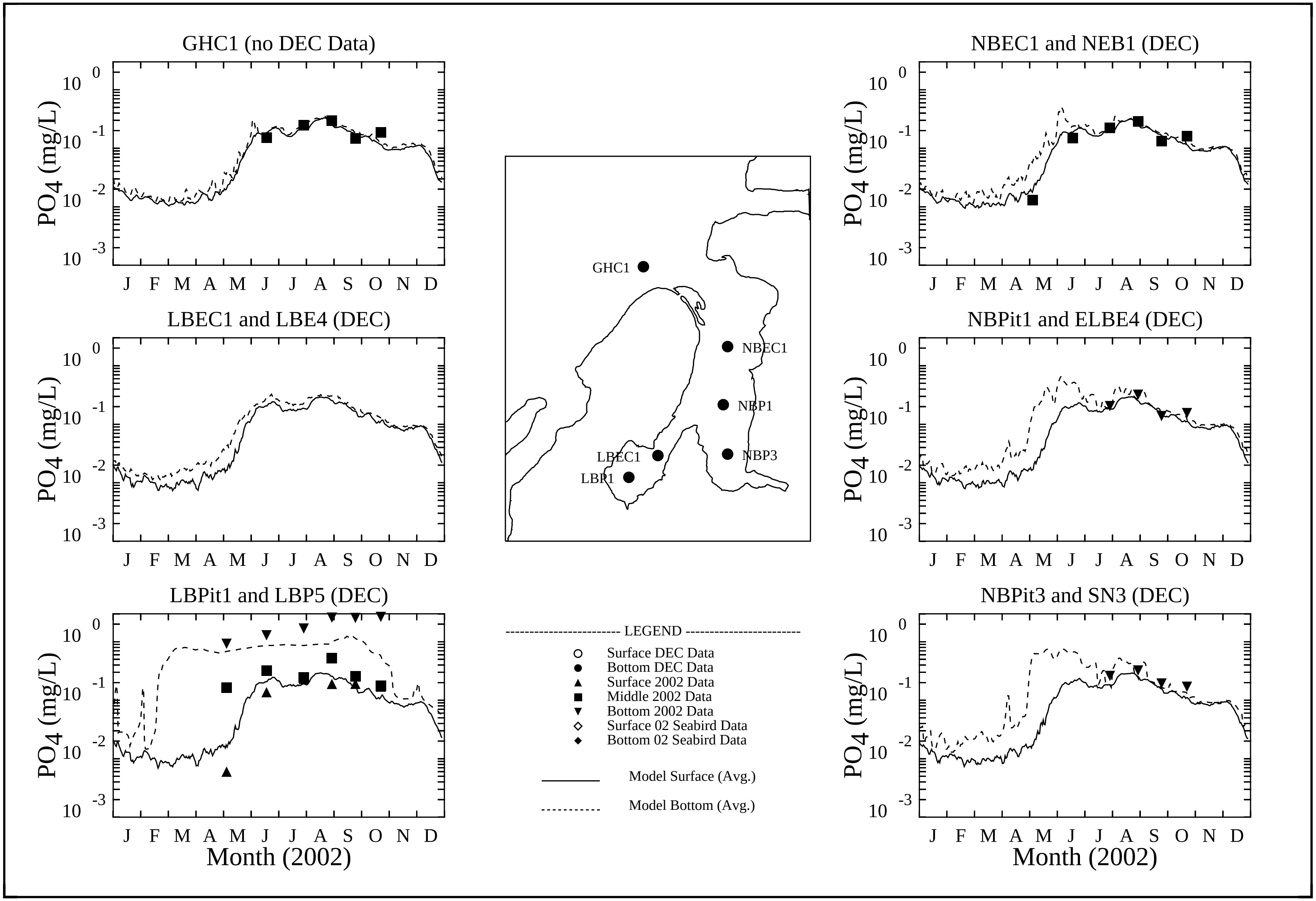



Figure 2-20. Time Series Comparison of Model Versus Data for Phosphate

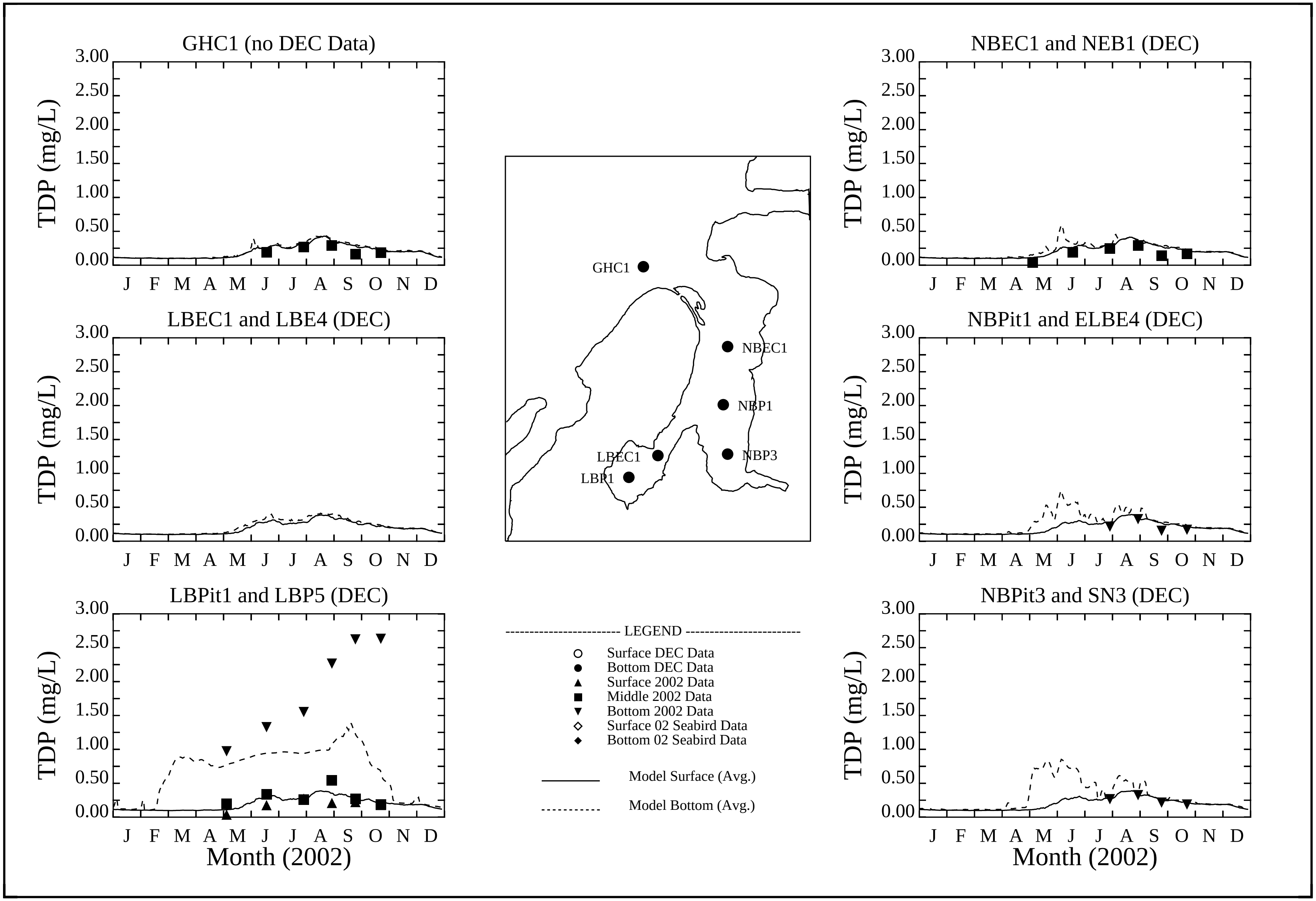



Figure 2-21. Time Series Comparison of Model Versus Data for Total Dissolved Phosphorus

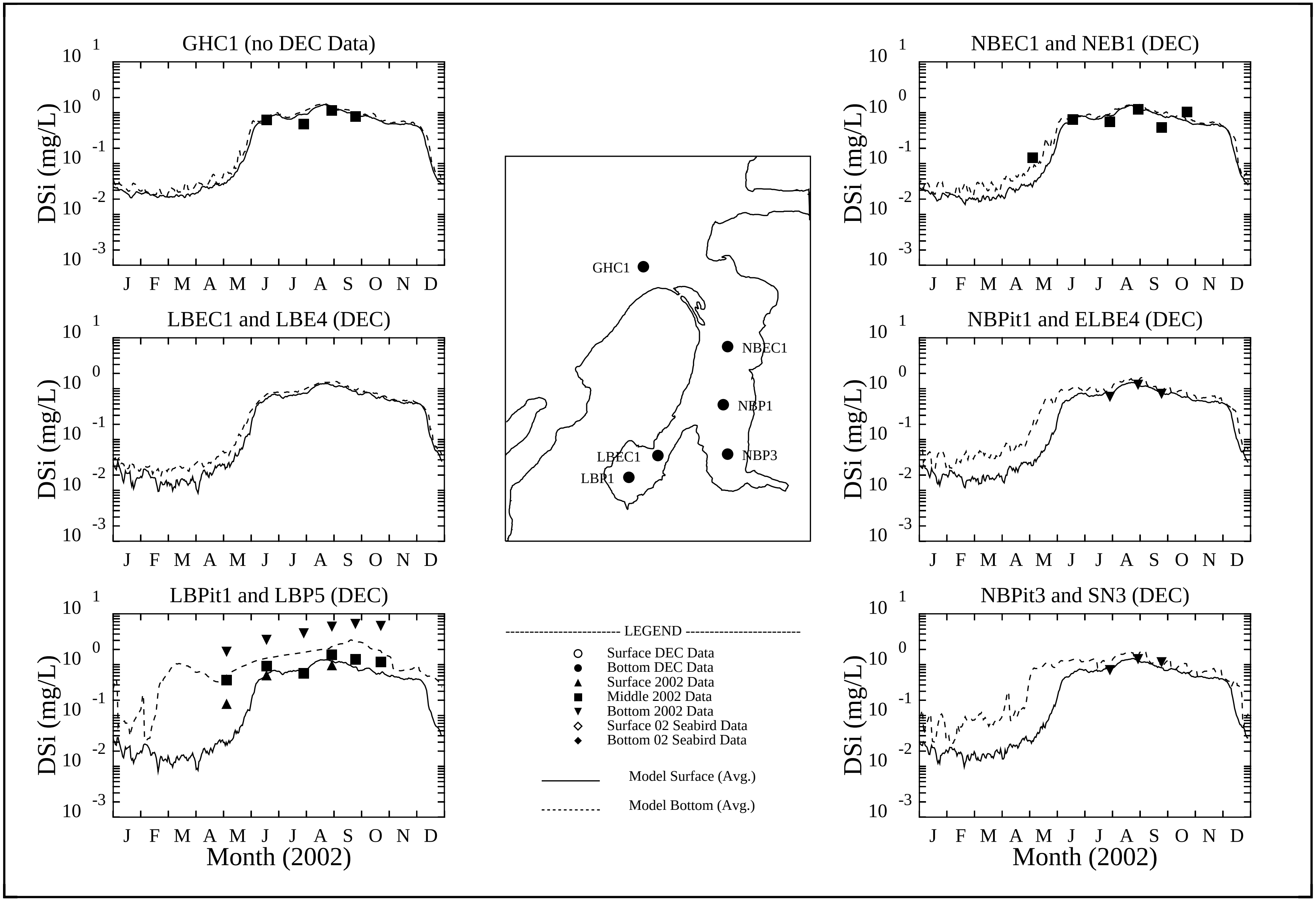



Figure 2-22. Time Series Comparison of Model Versus Data for Dissolved Silica

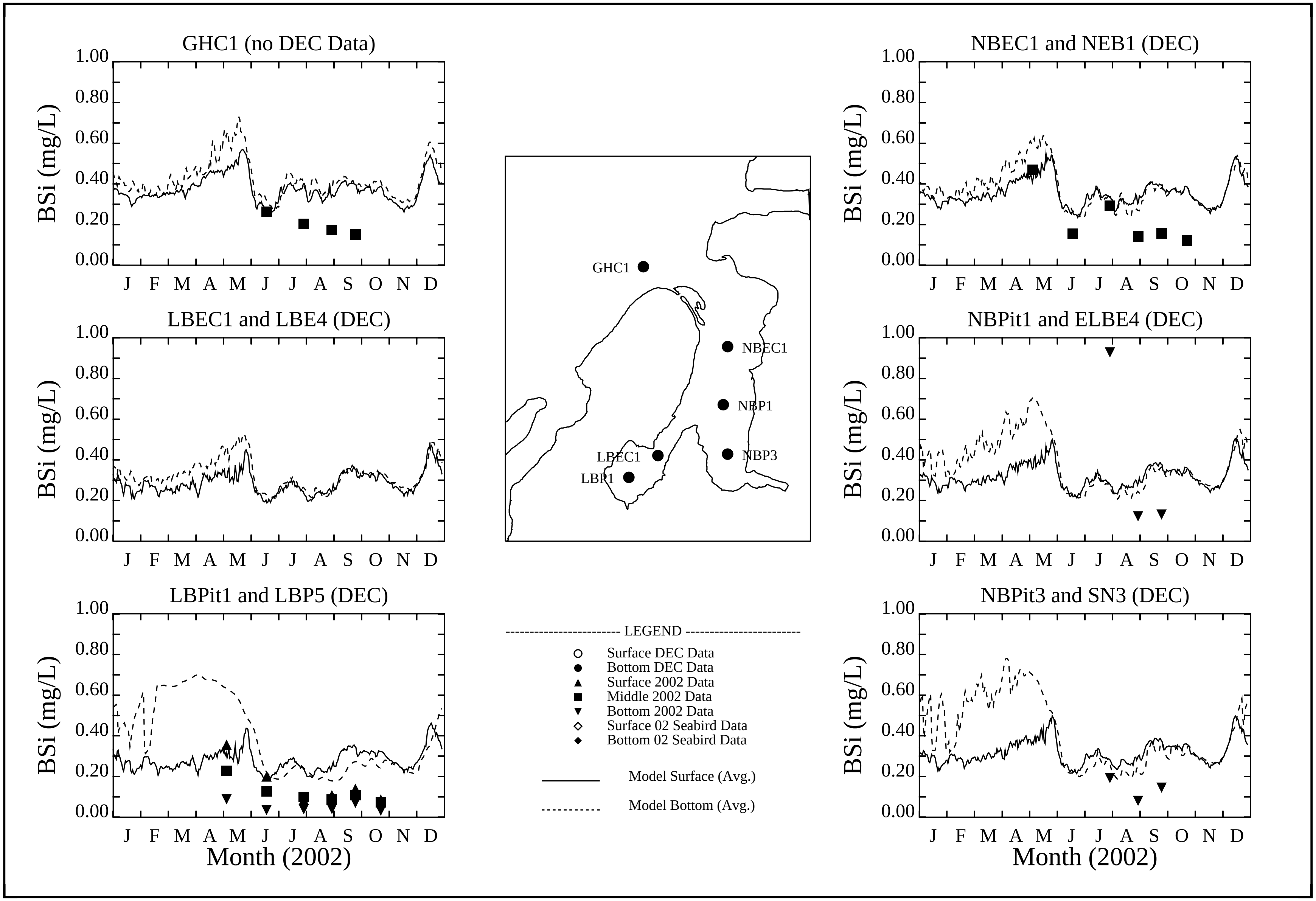



Figure 2-23. Time Series Comparison of Model Versus Data for Biogenic Silica

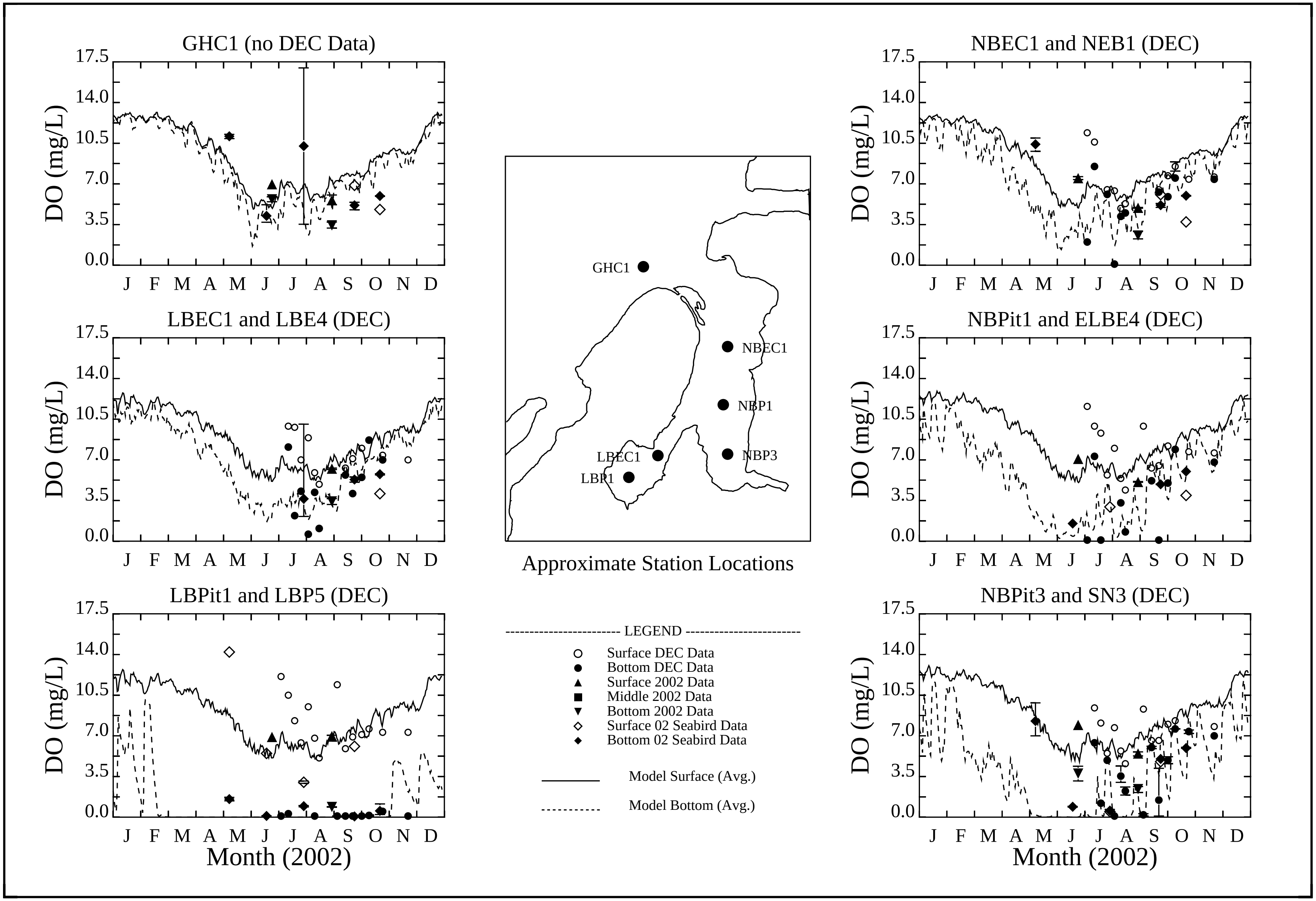



Figure 2-24. Time Series Comparison of Model Versus Data for Dissolved Oxygen

is able to reproduce much of the data, and computes large changes in the bottom DO as a result of mixing events. The most stratification is observed in the Little Bay pit. Anoxia is measured in the majority of the bottom water samples. The model reproduces this feature, calculating anoxia from late-February until late-October. Data indicates that anoxia can even occur during November. Since the model calculates that the surface and bottom water temperatures become the same earlier in the year than the data indicates (Figure 2-6), resulting in surface to bottom mixing, the model is not able to calculate anoxic conditions for as long as the data suggest. Overall, the model reproduces the DO data reasonably well.

Aside from surface, mid-depth and bottom data, several vertical profiles of temperature, salinity and DO were taken during 2002. Figures 2-25 through 2-27 present some model versus data comparisons to the vertical profile data. Model comparisons to this type of data are a more difficult challenge than the time series figures presented earlier. The eye can forgive certain differences between model and data in a times series figure when the model can reproduce the general pattern of the data even if the timing is somewhat early or delayed. In a vertical profile comparison, the model is attempting to reproduce an exact moment in time in a particular place. The following figures present some of the better model to data comparisons using a one-day average of model results to compare with the data. Additional model to data comparisons, both good and bad, are presented in Appendix A.

Figure 2-25 presents vertical profile comparisons for temperature, salinity and DO in Grass Hassock Channel during June. The temperature data show little vertical variation with temperatures between 20 and 21 $^{o}$C. The model reproduces the data very well. The salinity data also shows little vertical differences, but with slightly slower salinity closer to the surface. The model reproduces these data fairly well, only over estimating the salinity by approximately 1.0 ppt. The dissolved oxygen is also similar top to bottom and the model reproduces these data as well.

Vertical profiles for the same data in June in the Norton Basin pits are shown in Figure 2-26. The temperature and salinity data do not show much vertical stratification, but stations NBP1 and NBP2 indicate vertical stratification in the DO concentrations. The model reproduces the temperature reasonably well, but underestimates the temperature near the bottom. Salinity is reproduced well by the model at stations NBP1 and NBP2 except for the curious bottom measurements. The salinity data at station NBP3 is significantly lower than at the other two pit stations, and is most likely erroneous data because this difference does not occur in the majority of the other surveys. The model reproduces the dissolved oxygen data at stations NBP1 and NBP2 very well, matching the shape and magnitude of the vertical profile.

The last vertical profile figure to be presented is Figure 2-27 for the June survey in Little Bay. The model is able to reproduce the surface and bottom temperatures, but cannot reproduce the strong temperature gradient at mid depth. The model reproduces the surface salinity, but the bottom salinity is underestimated. Despite not exactly matching the temperature and salinity, the model reproduces the DO data very well.

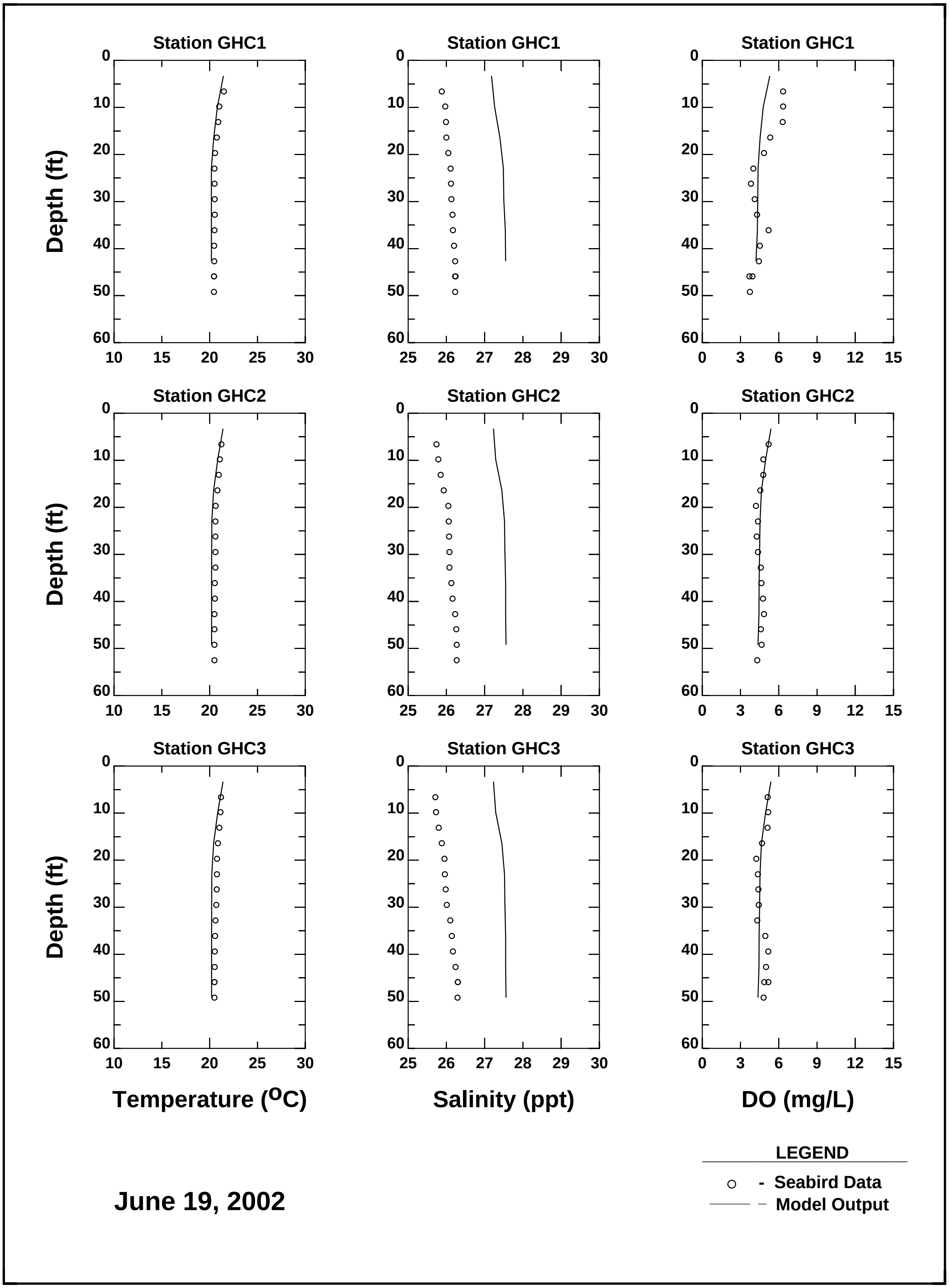



Figure 2-25. Norton Basin Model, Vertical Profile in Grass Hassock Channel

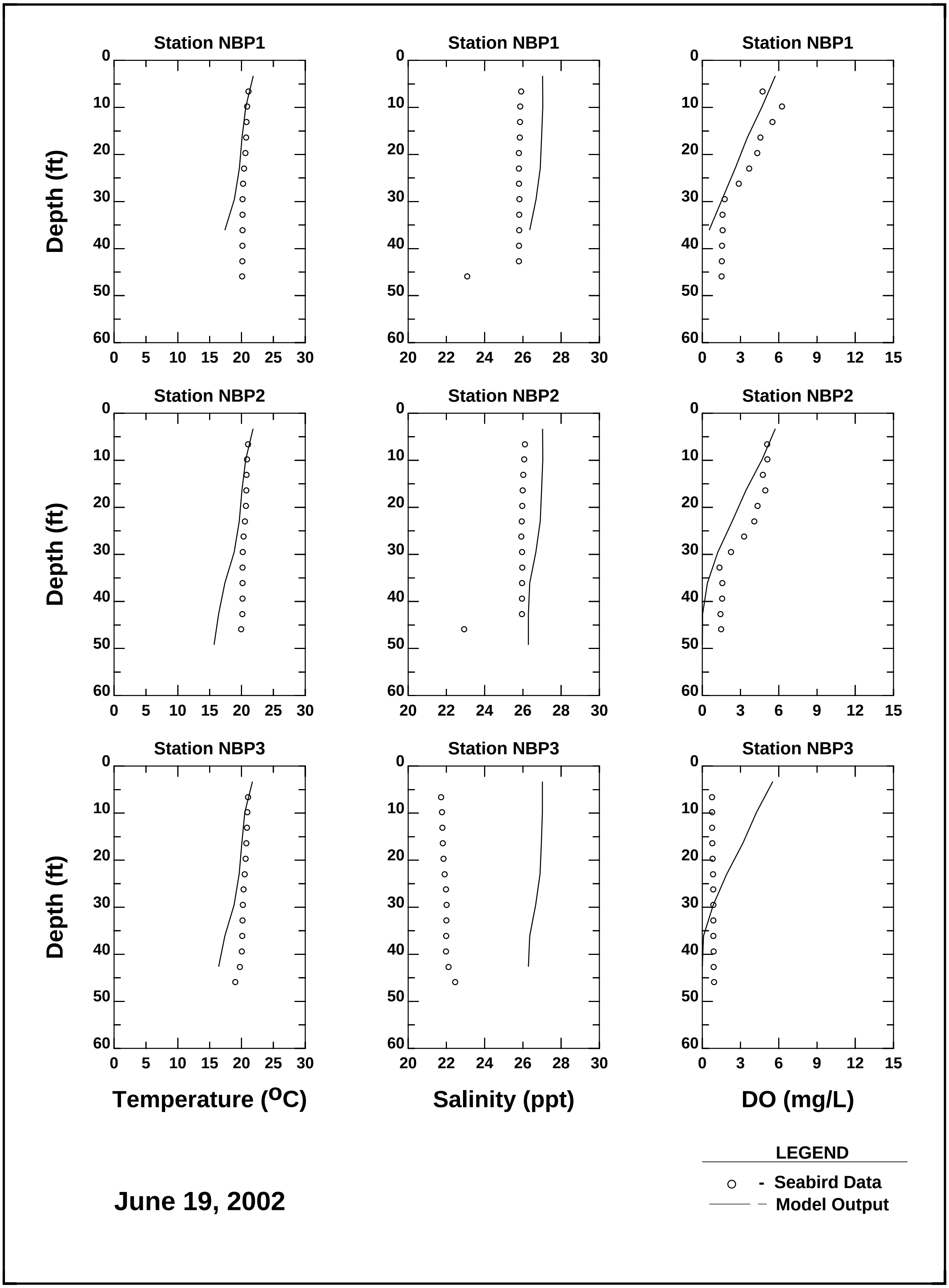



Figure 2-26. Norton Basin Model, Vertical Profile in Norton Basin Pits

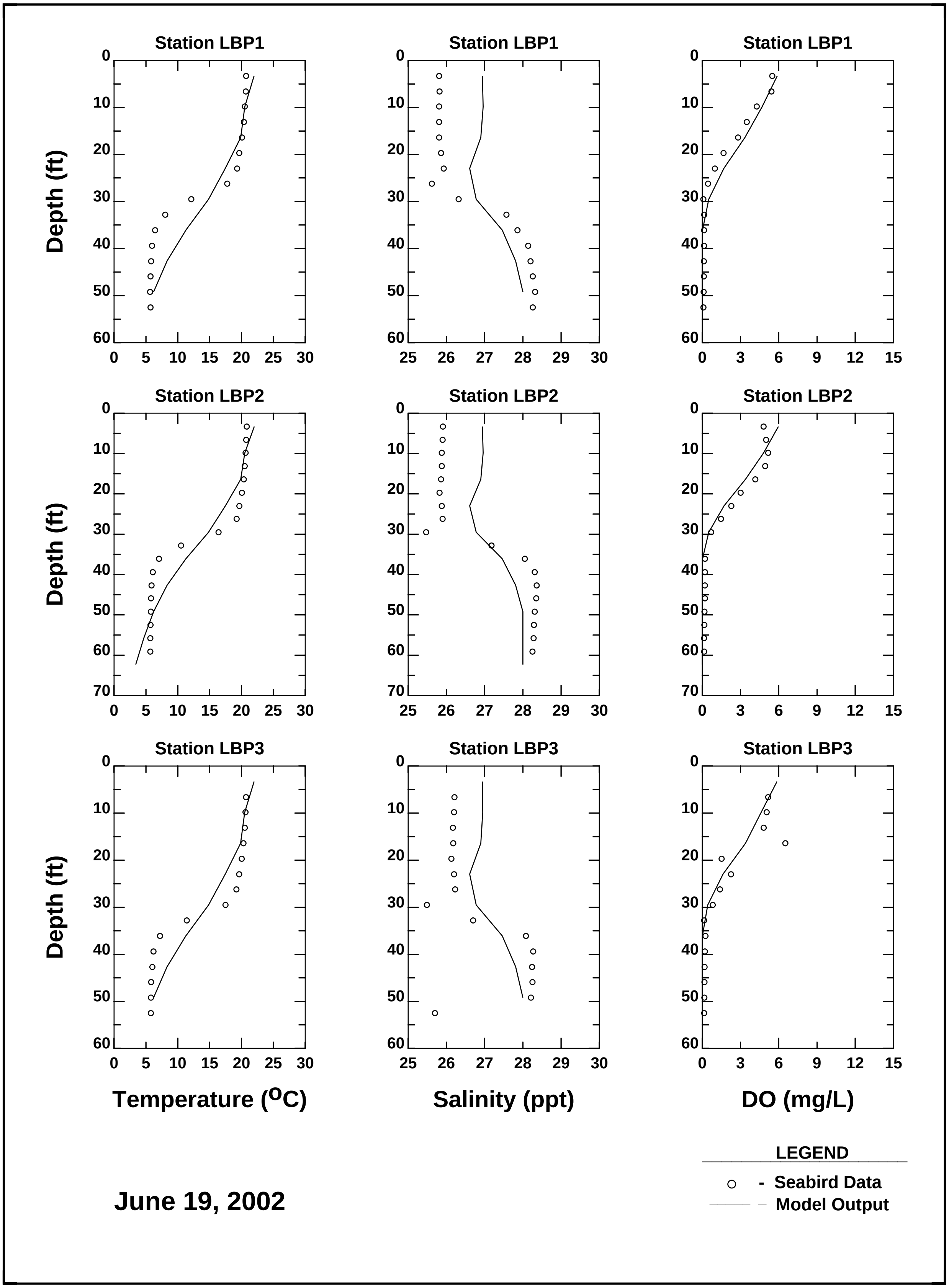



Figure 2-27. Norton Basin Model, Vertical Profile in Little Bay Pits

## SECTION 3

# RESULTS

With the model satisfactorily calibrated, a series of projection runs were completed. Due to the assigned model bathymetry in the Z-level model, fill depths could only be analyzed at two-meter increments, although one sensitivity was run with one-meter increments. The goal of the recontouring analysis was to find the optimum depth to which the borrow pits should be recontoured based on improvements in water quality (i.e., DO, $NH_3$), which would translate into improved habitat. Improving water quality hinged on the ability of recontouring to break up the existing vertical density stratification. The conditions that were examined were as follows:

a. baseline
b. create a dredged channel into Norton Basin (all of the remaining scenarios included this channel)
c. recontour Norton Basin and Little Bay to 8 m below MSL (23.5 ft. below MLLW)
d. recontour Norton Basin and Little Bay to 6 m below MSL (17 ft. below MLLW)
e. recontour Norton Basin and Little Bay to 4 m below MSL (10.5 ft. below MLLW)
f. recontour Little Bay to 8 m below MSL (23.5 ft. below MLLW)
g. recontour Little Bay to 4 m below MSL (10.5 ft. below MLLW)
h. recontour Norton Basin to 8 m below MSL (23.5 ft. below MLLW)
i. recontour Norton Basin to 4 m below MSL (10.5 ft. below MLLW)
j. sloping recontour of Norton Basin and Little Bay from 4 m to 6 m below MSL (10.5 to 17 ft. below MLLW)
k. sloping recontour of Norton Basin and Little Bay from 3 m to 6 m (1 m increments) (7 ft. to 17 ft. below MLLW)
l. shear stress analysis (preferred option)

The baseline was the existing, or 2002, conditions. The first scenario was the creation of a deeper channel into Norton Basin. The remaining scenarios attempted to bound the possibilities for recontouring scenarios. Eight meters below MSL (26 ft.) was chosen as the minimum amount of recontouring because the pycnocline in Little Bay is observed at approximately 30 ft. Four meters below MSL (13 ft.; approximately 10.5 ft. below MLLW) was chosen as the maximum level of recontouring because a shallower depth might allow enough light to penetrate to the bottom to allow *Ulva lactuca*, a nuisance macro-algae, to grow, which would most likely not improve habitat.

The model bathymetry is set up with a datum of Mean Sea Level (MSL). Table 3-1 presents MSL compared to other datum for conversion purposes. The datum are based on tidal datums at Sandy Hook.

**Table 3-1. Elevations of Tidal Datums**

| Datum | Meters | Feet |
|---|---|---|
| North American Vertical Datum – 1988 (NAVD) | 0.858 | 2.815 |
| Mean Sea Level (MSL) | 0.785 | 2.575 |
| Mean Tide Level (MTL) | 0.775 | 2.543 |
| Mean Low Water (MLW) | 0.058 | 0.190 |
| Mean Lower Low Water (MLLW) | 0.000 | 0.000 |

The projections assume that the fill material, at least in the top 10 cm, is similar to the sediment already in the basins. The model is run to quasi sediment equilibrium (8 years), with the understanding that covering the existing sediment that has a high organic content with clean sand has only a temporary effect. In the long-term, a certain amount of organic material will settle onto the new bottom and may have some impact on future water quality conditions. No attempt was made to model any contaminants that may or may not be associated with the fill material.

The goal of the recontouring scenarios is to improve biological habitat. Under baseline conditions, density stratification contributes to poor vertical mixing in Norton Basin and Little Bay, which contributes to low dissolved oxygen and even anoxia. USEPA DO criteria developed for the Virginian Province set a minimum DO concentration of 2.3 mg/L for juvenile fish survival and 4.8 mg/L for larval growth. The NYSDEC has set a DO standard of never less than 5.0 mg/L for Norton Basin and Little Bay. These concentrations provide a benchmark with which to compare model results for DO, and to assess whether improvements to habitat will occur.

Low dissolved oxygen can result in increased ammonia fluxes from the sediment. These ammonia fluxes coupled with poor mixing result in high ammonia concentrations, which can lead to unionized ammonia toxicity. The amount of unionized ammonia varies greatly with temperature and pH. In Little Bay at a temperature of 7 °C and a pH of 7.4 the total ammonia would need to be 8.97 mg N/L to have unionized ammonia concentrations high enough to violate the four-day average chronic criteria of 0.035 mg $NH_3$/L. At a pH of 7.9 the total ammonia nitrogen would need to be 2.86 mg N/L. Ammonia concentrations as high as 10.4 mg/L were measured in Little Bay. In Norton Basin, where bottom temperatures can be much warmer, a temperature of 22 °C and a pH of 7.9 requires a total ammonia concentration of 0.95 mg N/L to exceed the chronic criteria concentration. Ammonia concentrations as high as 3.05 mg/L were measured in Norton Basin Pits.

In order to improve habitat, the goals are to increase dissolved oxygen levels and reduce ammonia concentrations in Norton Basin and Little Bay. One of the ways to improve the water quality is to improve the vertical mixing in these areas. One way of achieving more vertical mixing is to recontour the bottom bathymetry.

Baseline

The baseline is the calibration results for 2002. Four locations have been chosen to examine the effects of the projection scenarios on water quality: the entrance channel to Little Bay at a depth of approximately 8 m below MSL (26 ft., model depth at MSL), the entrance channel to Norton Basin at a depth of approximately 10 m (33 ft.), the Little Bay Pit at 18 m (59 ft.), and Norton Basin Pit 3 at 14 m (46 ft.). Figures 3-1, 3-2 and 3-3 present the temperature, DO, and $NH_3$ model baseline results for comparison to the projection results.

A sensitivity was run for the calibration to assess the sensitivity of model results to the vertical segmentation increment. The calibrated increment was changed from 2 m to 1 m and the bathymetry was modified accordingly. The surface layer required 2 m to accommodate the tidal range. The sensitivity showed that increasing the number of vertical layers tended to increase vertical mixing. The increased mixing made the model comparison to the data less favorable and more than doubled the model execution time. This sensitivity showed that increasing the number of vertical layers did not improve model performance.

Dredged Channel

Due to constraints from the refinement of the grid, the channel for this simulation was made larger than initially planned. The channel width was approximately 170 ft. and the depth was increased from 13 ft. to 20 ft. below MSL. The dredged channel scenario does not improve water quality in Norton Basin and Little Bay. A comparison between Figures 3-1 and 3-4 show that the change in temperature due to deepening the channel is minimal. The temperature results indicate that increasing the size of the entrance to the bay does not enhance the vertical mixing. As a consequence water quality in Norton Basin and Little Bay

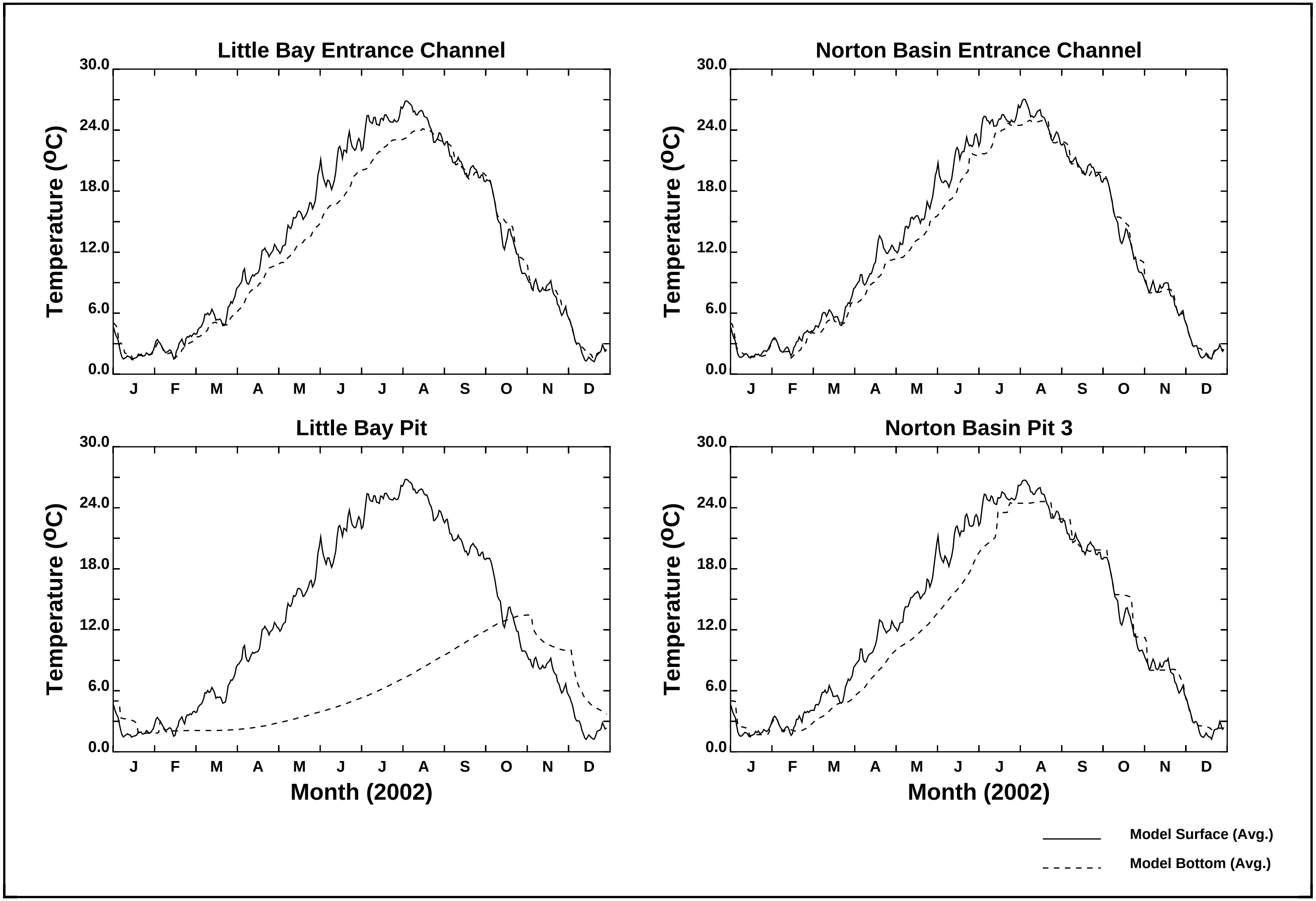



Figure 3-1. - Temperature ($^{o}$C)
Baseline Conditions

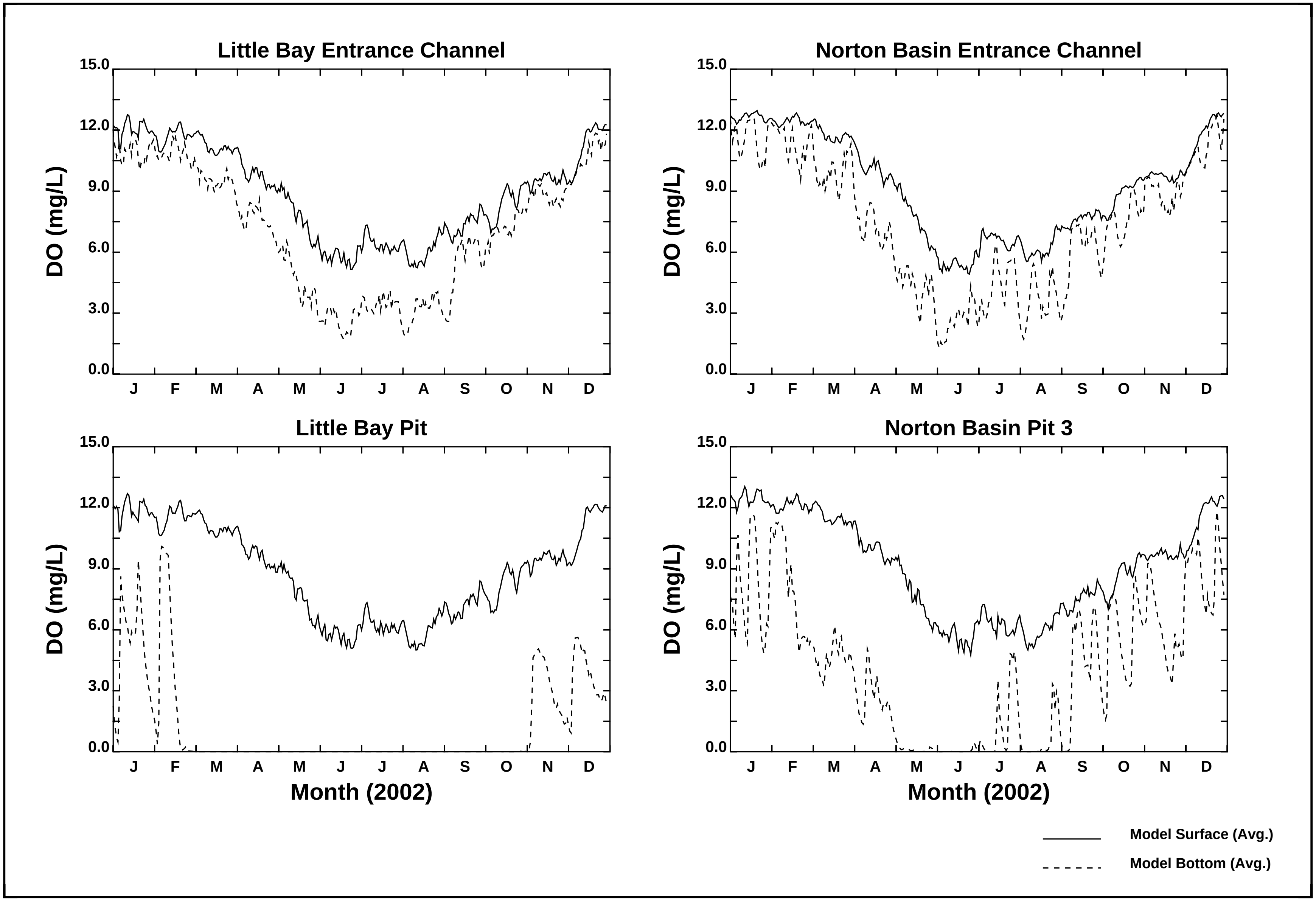



Figure 3-2. - Dissolved Oxygen (mg/L)
Baseline Conditions

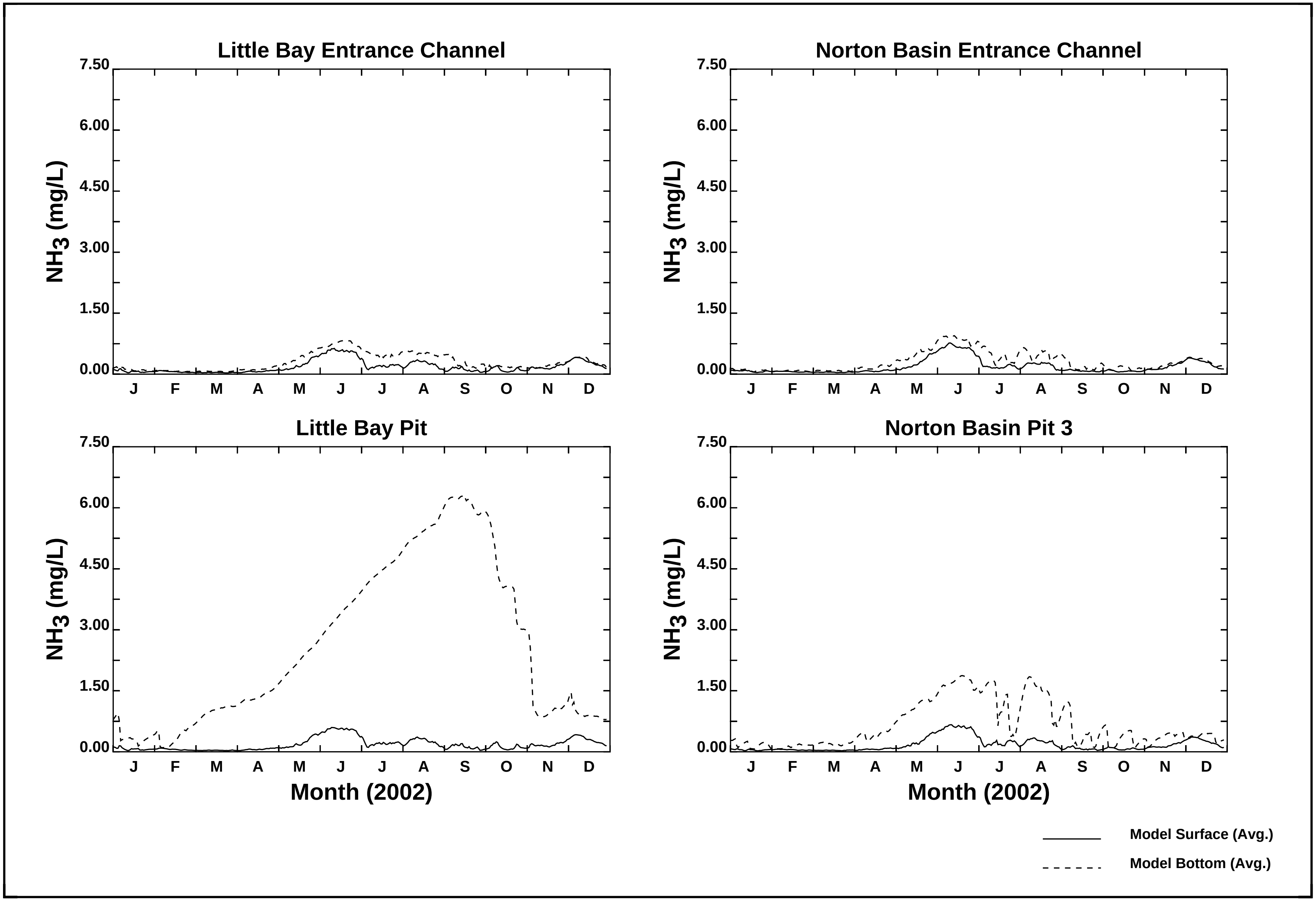



Figure 3-3. - Ammonia (mg/L)
Baseline Conditions

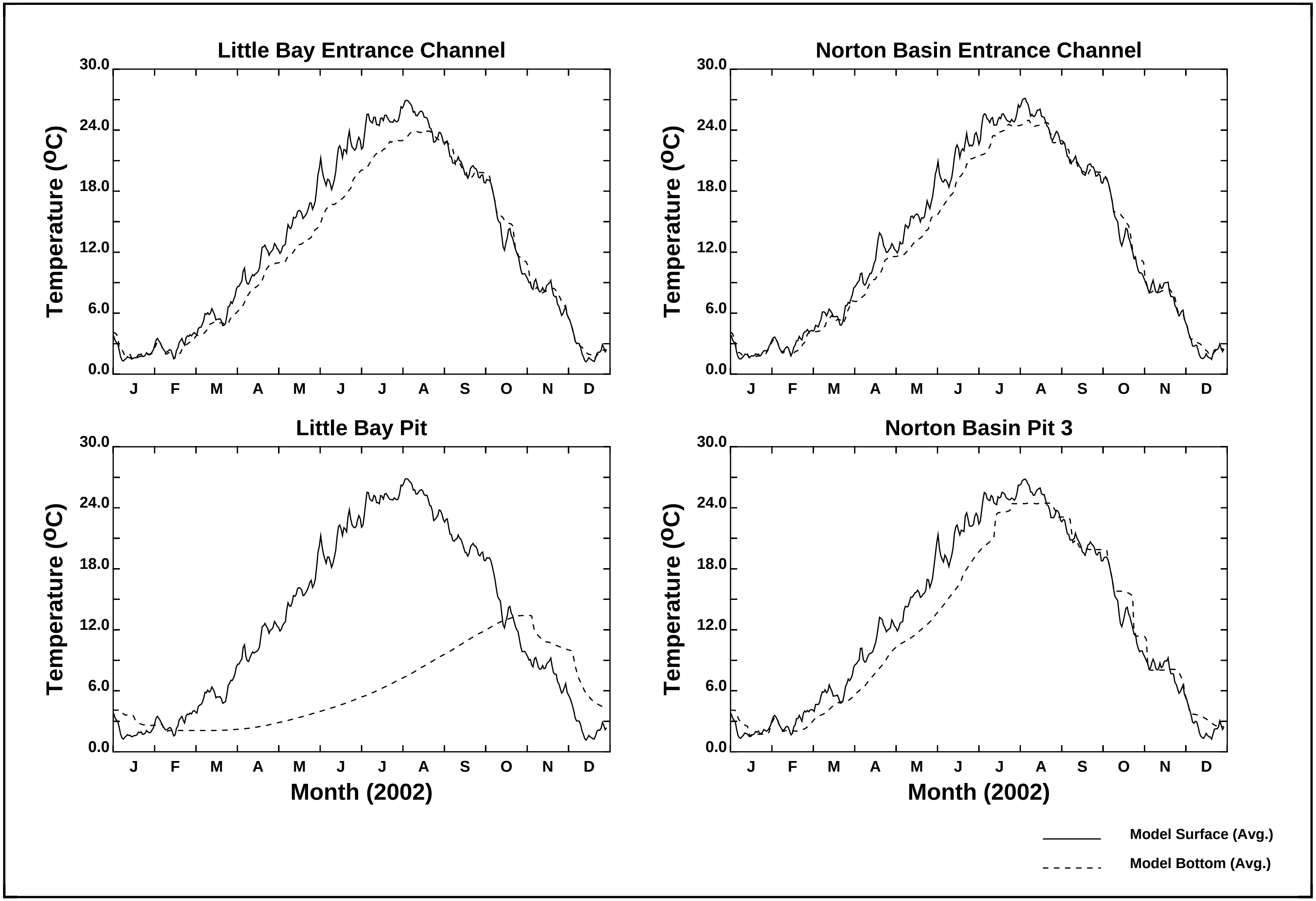



Figure 3-4. - Temperature ($^{o}$C)
Dredged Channel

does not improve, as shown in Figures 3-5 and 3-6. Only minor differences can be observed between the baseline and dredged channel scenarios.

Concerns were raised that the modeled channel did not match the proposed channel closely enough. As a sensitivity, the model grid was reconfigured with a narrower channel, reducing the width from 170 ft to 80 ft. This change affected only the areas close to the channel. The impacts in the borrow pits, which are the areas of concern, were negligible. This is for their evidence that the borrow pits are so isolated that modifications to the entrance channel would not result in improved water quality in the borrow pits.

<u>Recontour Norton Basin and Little Bay to 8 m below MSL</u>

Recontouring both basins to 8 m below MSL reduces the temperature stratification in both Norton Basin and Little Bay (Figure 3-7). The recontouring reduces the level of vertical density stratification, but does not eliminate it. Improvement in water quality, in terms of dissolved oxygen levels, is calculated to occur due to recontouring both areas to 8 m below MSL (Figure 3-8). Since very little stratification is required to reduce mixing, the model continues to calculate periods of hypoxia. However, anoxia is no longer calculated by the model in Little Bay and Norton Basin. The entrance channel to Little Bay is calculated to have slightly lower DO in this scenario. Figure 3-9 shows ammonia concentrations in both Norton Basin and Little Bay are reduced to a level that would most likely not violate the chronic unionized ammonia criterion.

A sensitivity was completed for the recontour to 8 m scenario, similar to the calibration sensitivity, where the vertical segmentation was increased from 2 m intervals to 1 m intervals. As in the calibration sensitivity, vertical mixing increased. The increased vertical mixing resulted in improved water quality in the 1 m scenario versus the 2 m scenario. Since the calibration scenario with 1 m vertical increments did not compare well to the data, it is unlikely that the 1 m sensitivity for the 8 m recontouring scenario produces better results than the 2 m projection. Also, the 1 m increment scenario produces results that are less conservative (show more improvement) than the 2 m results, so the 2 m result is preferred in this analysis.

<u>Recontour Norton Basin and Little Bay to 6m below MSL</u>

Figure 3-10 presents the model results for surface and bottom temperature after recontouring Norton Basin and Little Bay to 6 m below MSL. Recontouring to 6 m is more effective than recontouring to 8 m in reducing temperature stratification, although temperature stratification is not completely eliminated in the 6 m scenario. Figure 3-11 shows that DO concentrations improve over the 8 m scenario. While there are still excursion of DO less than 3.0 mg/L, these occur less often in the 6 m scenario than the 8 m

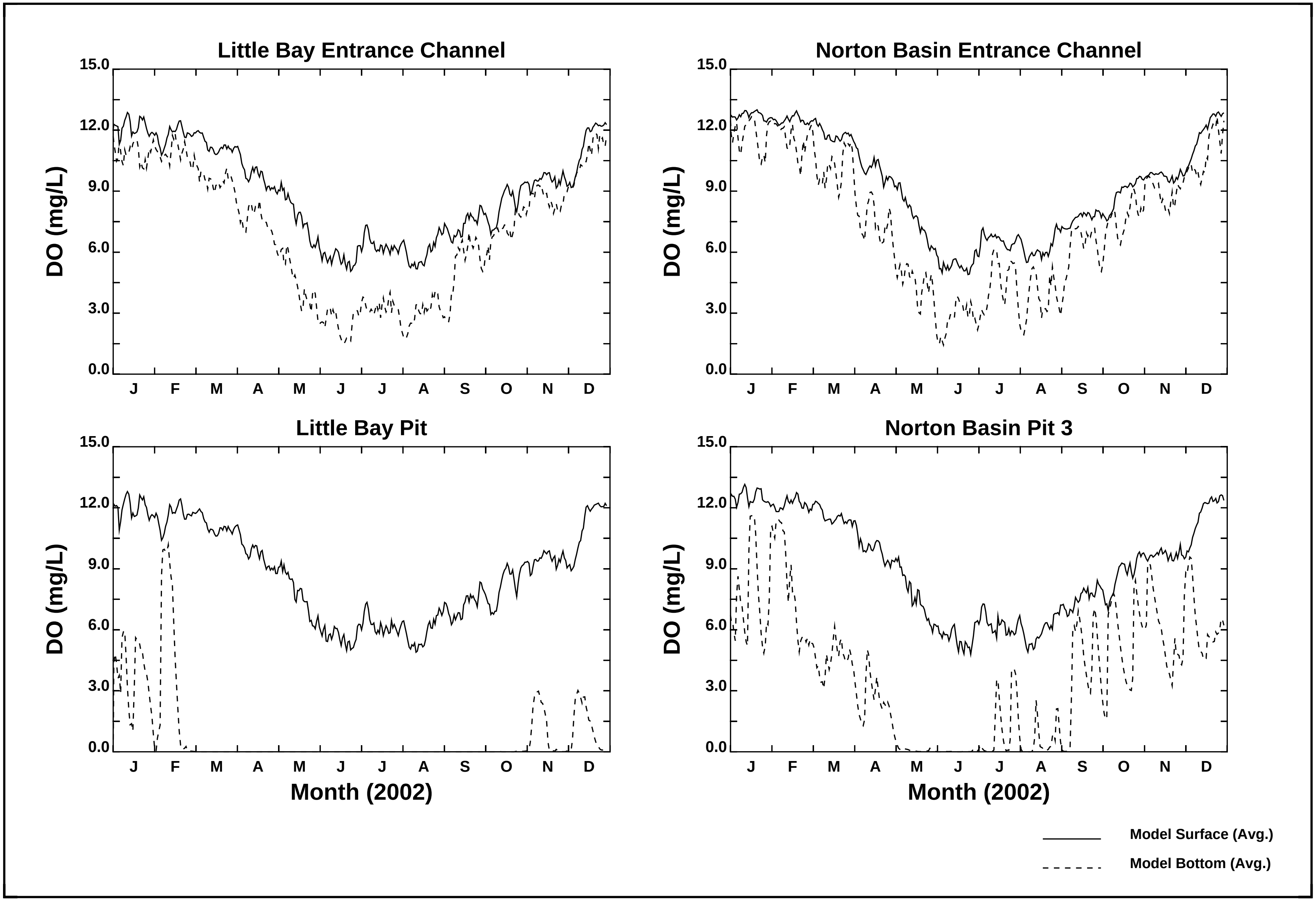



Figure 3-5. - Dissolved Oxygen (mg/L)
Dredged Channel

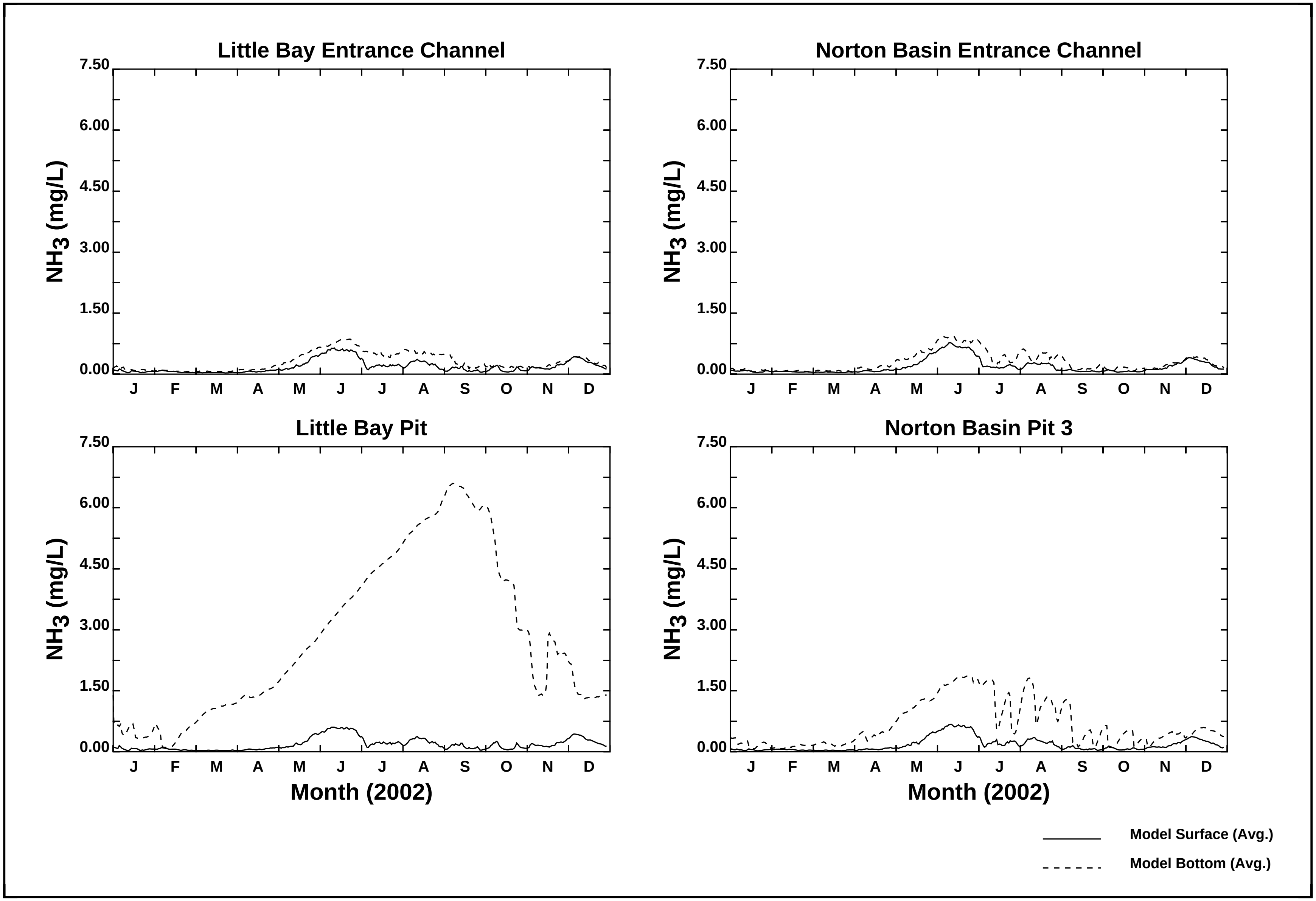



Figure 3-6. - Ammonia (mg/L)
Dredged Channel

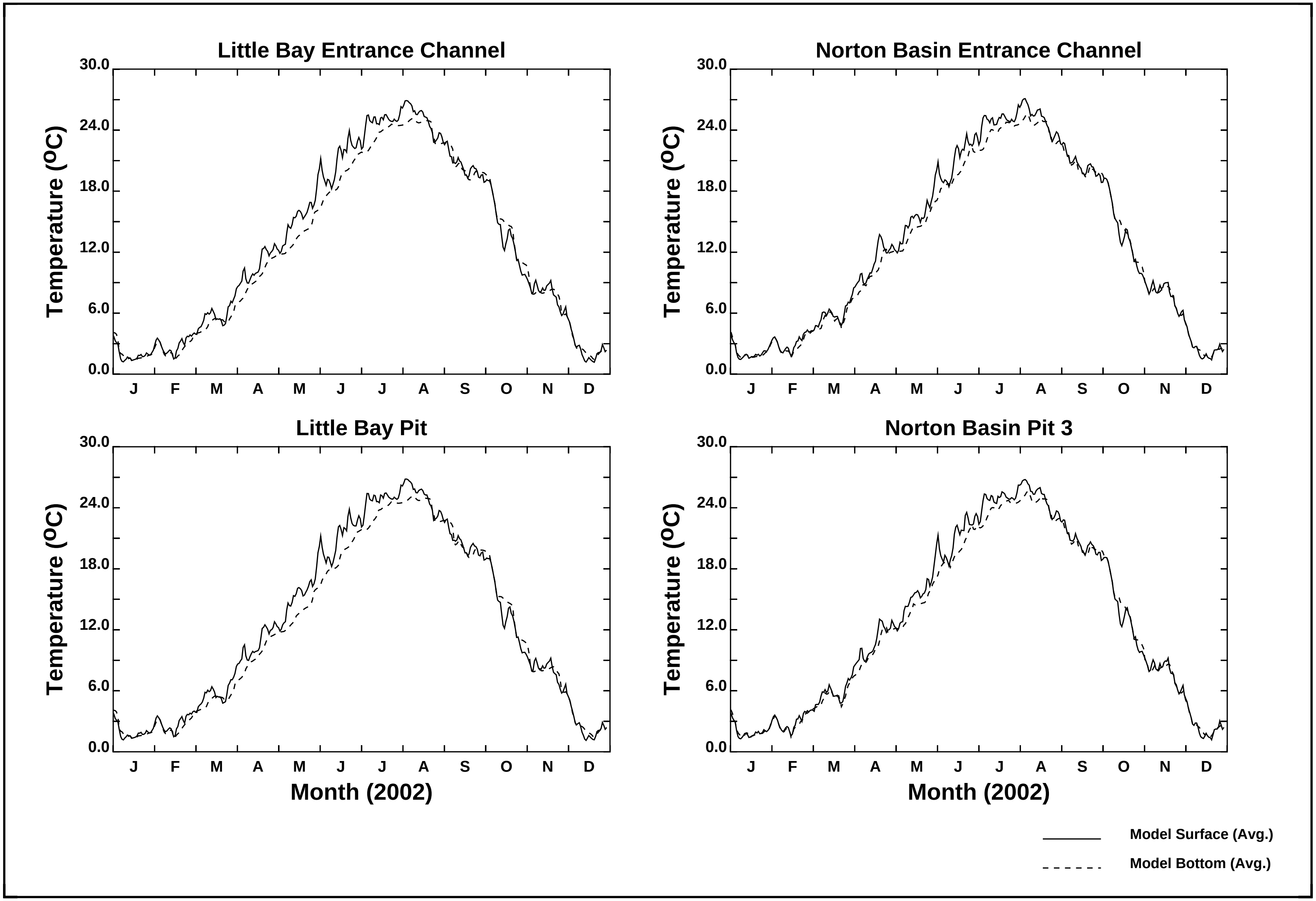



Figure 3-7. - Temperature ($^{o}$C)
Recontour Norton Basin and Little Bay to 8 m below MSL

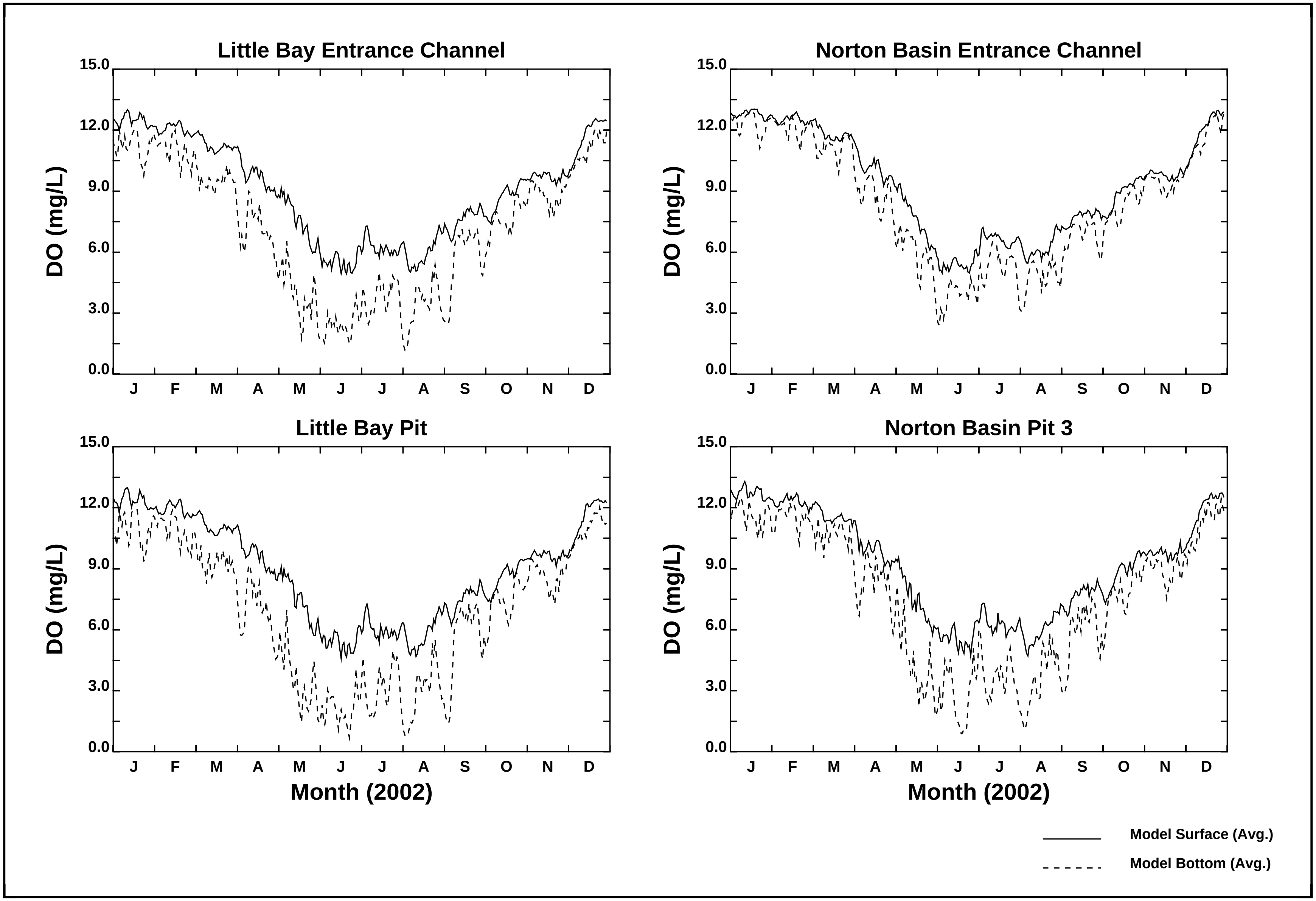



Figure 3-8. - Dissolved Oxygen (mg/L)
Recontour Norton Basin and Little Bay to 8 m below MSL

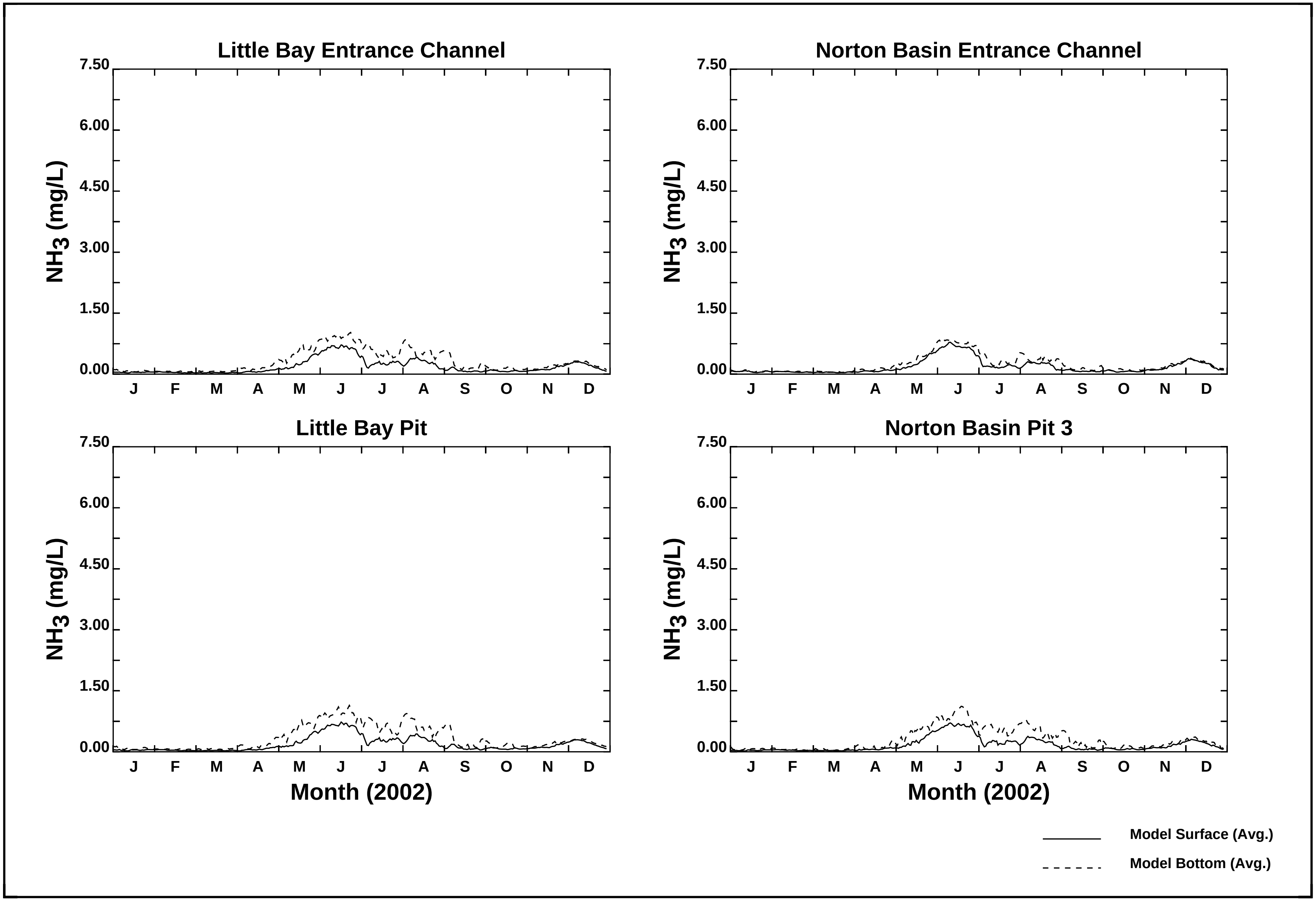



Figure 3-9. - Ammonia (mg/L)
Recontour Norton Basin and Little Bay to 8 m below MSL

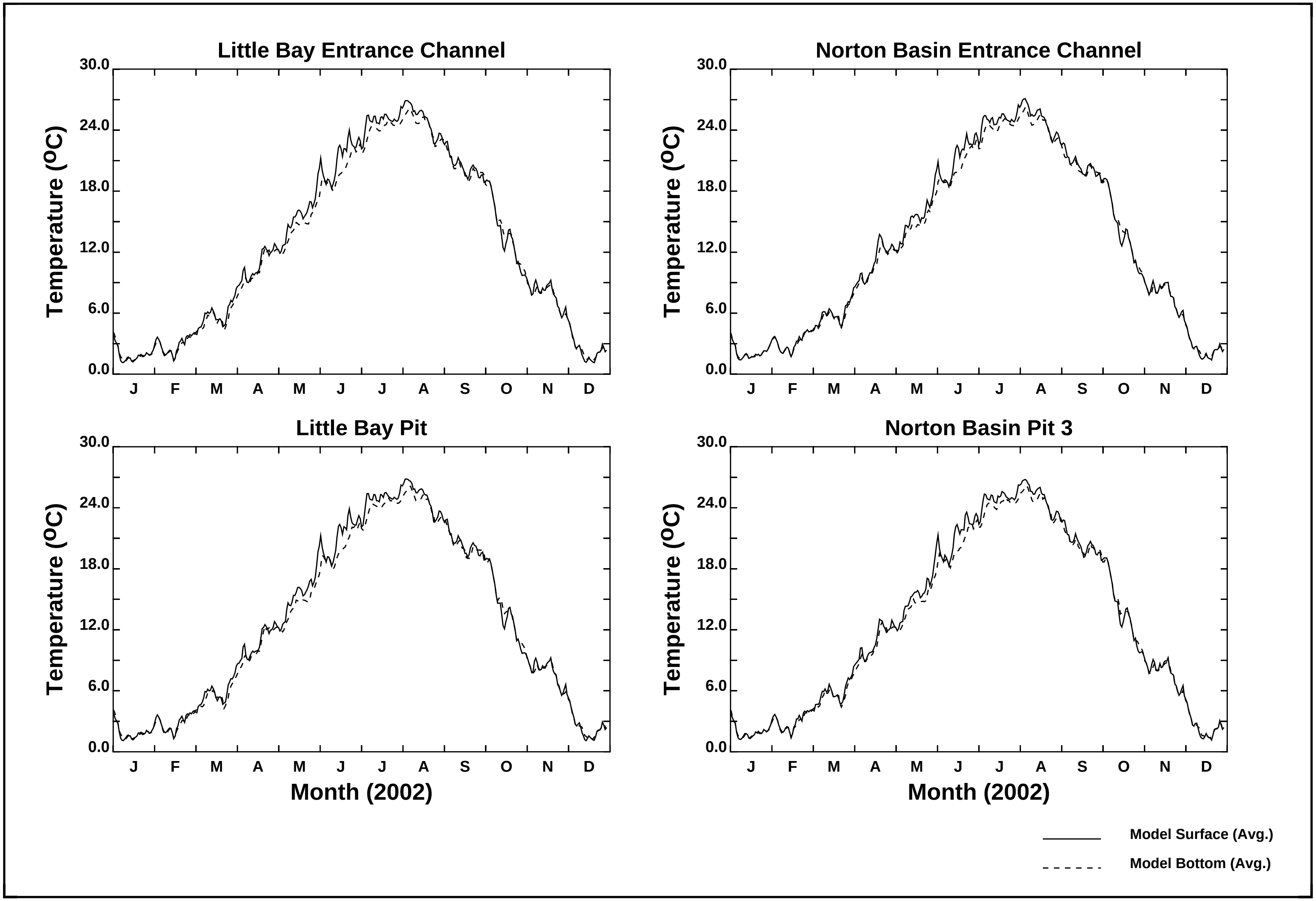



Figure 3-10. - Temperature ($^{O}$C)
Recontour Norton Basin and Little Bay to 6 m below MSL

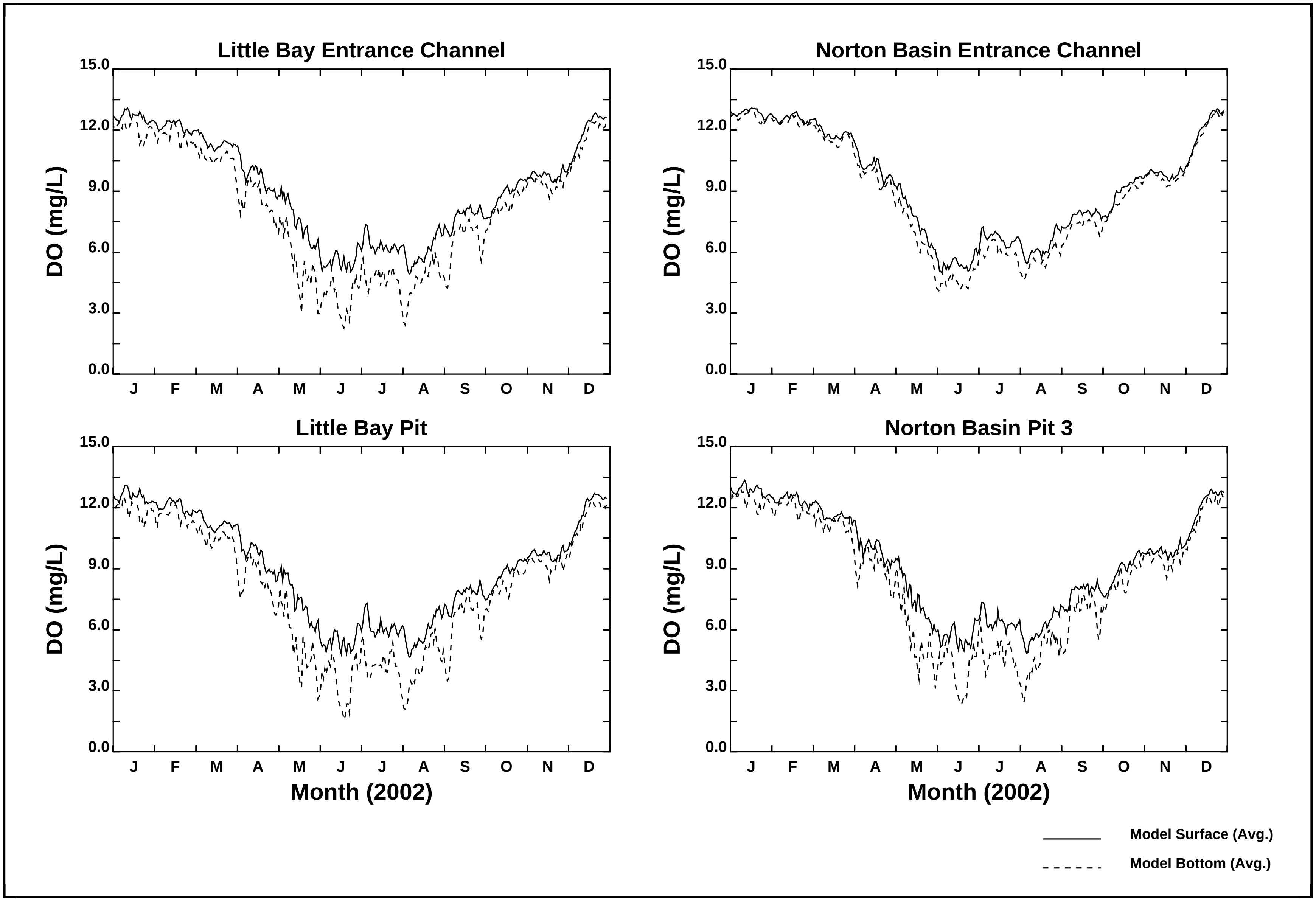



Figure 3-11. - Dissolved Oxygen (mg/L)
Recontour Norton Basin and Little Bay to 6 m below MSL

scenario. Figure 3-12 shows that ammonia concentrations in the borrow pits are reduced as a result of recontouring to 6 m below MSL.

<u>Recontour Norton Basin and Little Bay to 4 m below MSL</u>

Recontouring the basins to 4 m below MSL is very effective in reducing/eliminating vertical density stratification. Figure 3-13 shows virtually no temperature stratification. This allows improved mixing, which replenishes dissolved oxygen in the lower levels of the water column. The resulting water quality is similar to that observed in the shallow areas of Norton Basin where the system was already well mixed. Figure 3-14 shows the model does not calculate DO concentrations less than 4.0 mg/L at any of these locations. Ammonia concentrations are reduced to levels that are similar to the boundary conditions (Figure 3-15).

<u>Recontour Little Bay to 8 m below MSL</u>

Since Little Bay is more degraded in terms of water quality and habitat, it could be argued that only Little Bay should be recontoured. Recontouring Little Bay to 8 m below MSL reduces the temperature stratification in Little Bay as shown in Figure 3-16. This scenario shows that filling to only Little Bay to 8 m below MSL provides some improvement in dissolved oxygen. The improvement in Little Bay DO and $NH_3$ is similar to recontouring both Little Bay and Norton Basin to 8 m below MSL, presented in Figures 3-17 and 3-18. Norton Basin is relatively unaffected by the recontouring of Little Bay.

<u>Recontour Little Bay to 4 m below MSL</u>

Additional filling of Little Bay results in additional improvement in dissolved oxygen levels. Recontouring Little Bay to 4 m below MSL effectively reduces vertical stratification. Conditions in Norton Basin change very little due to the alterations in Little Bay. Figures 3-19, 3-20 and 3-21 present the results of this scenario.

<u>Recontour Norton Basin to 8 m below MSL</u>

The model results in Norton Basin due to recontouring the basin to 8 m below MSL are similar to the results in Norton Basin from recontouring both Little Bay and Norton Basin to 8 m below MSL. Temperature stratification is diminished (Figure 3-22), DO concentrations improve (Figure 3-23), anoxia is eliminated, but periods of hypoxia continue to occur. Ammonia concentrations, in the bottom waters of Norton Basin, decline (Figure 3-24). Recontouring only Norton Basin to 8 m below MSL has little impact on Little Bay.

<u>Recontour Norton Basin to 4 m below MSL</u>

Recontouring Norton Basin to 4 m below MSL virtually eliminates the temperature stratification in the basin, as shown in Figure 3-25. As a result the DO concentrations in Norton Basin are greatly improved (Figure 3-26). The model no longer computes hypoxia in

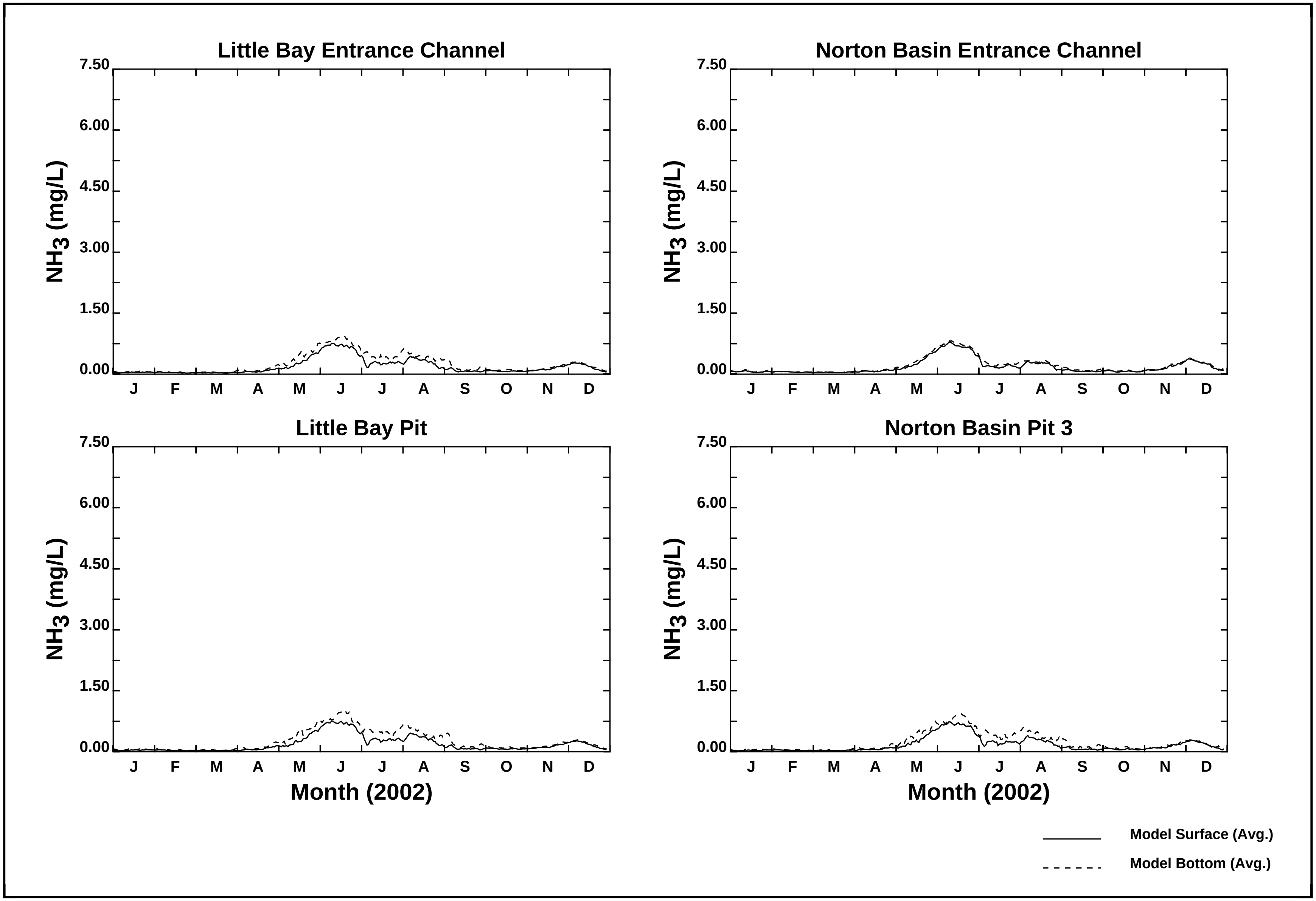



Figure 3-12. - Ammonia (mg/L)
Recontour Norton Basin and Little Bay to 6 m below MSL

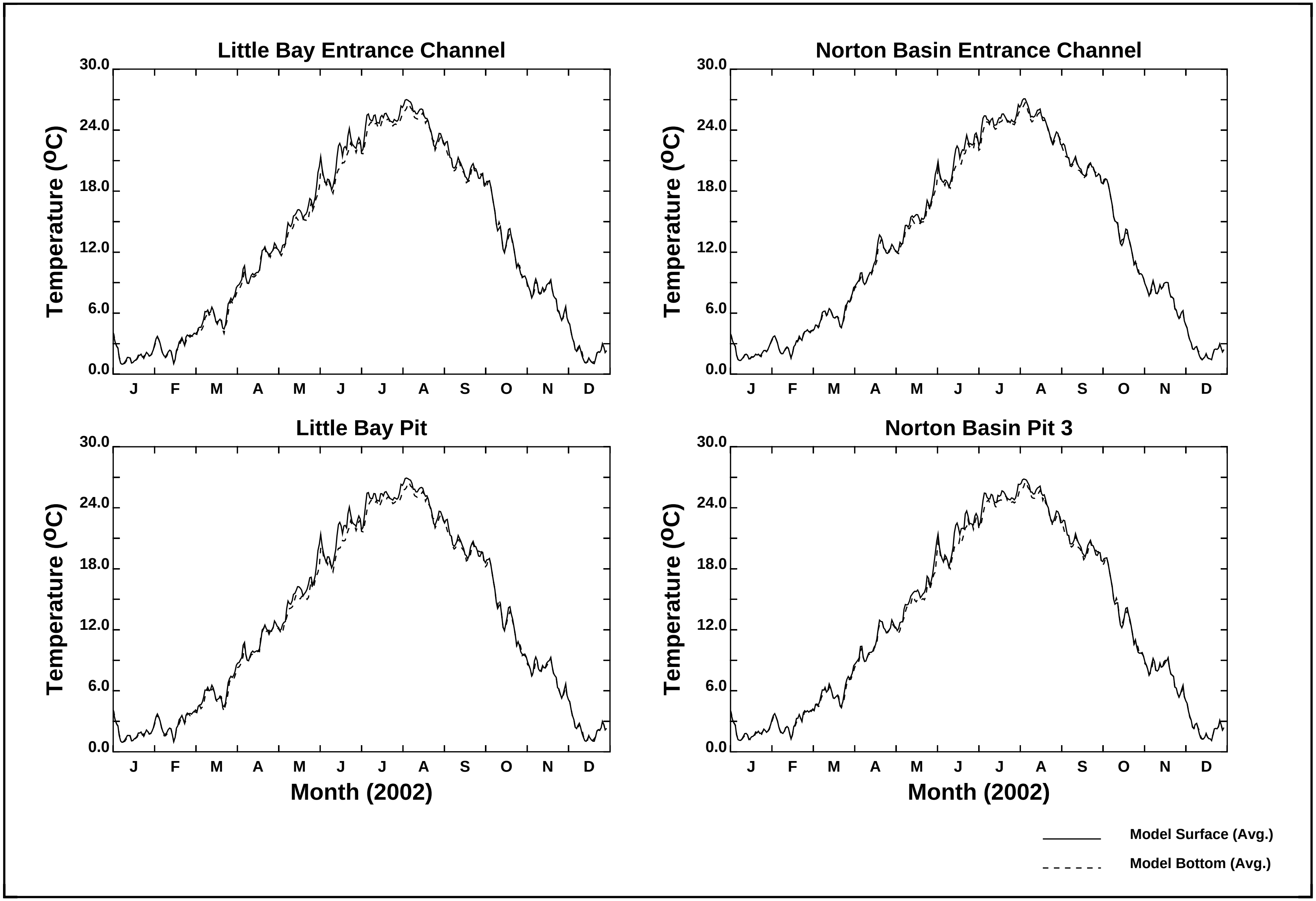



Figure 3-13. - Temperature (°C)
Recontour Norton Basin and Little Bay to 4 m below MSL

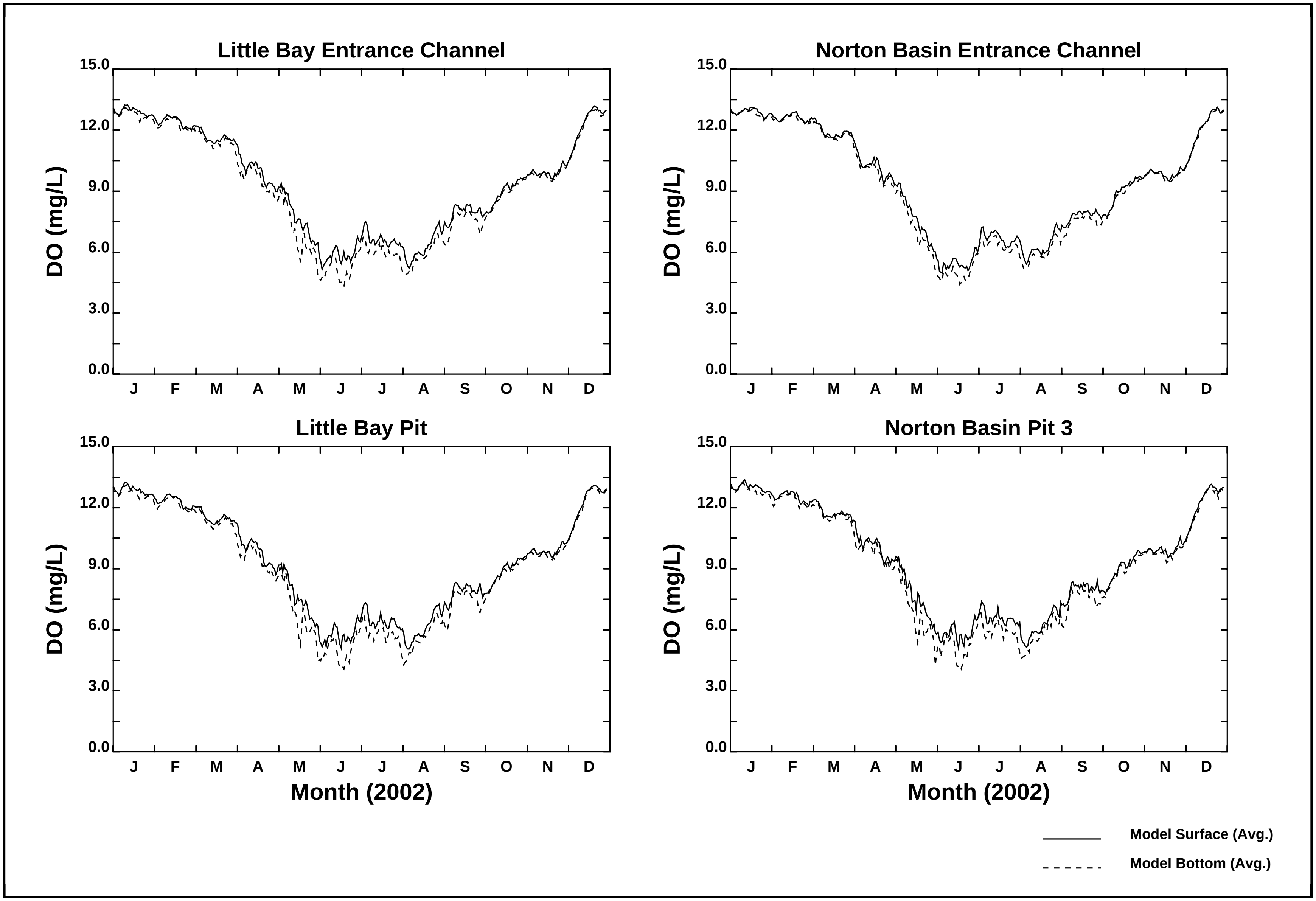



Figure 3-14. - Dissolved Oxygen (mg/L)
Recontour Norton Basin and Little Bay to 4 m below MSL

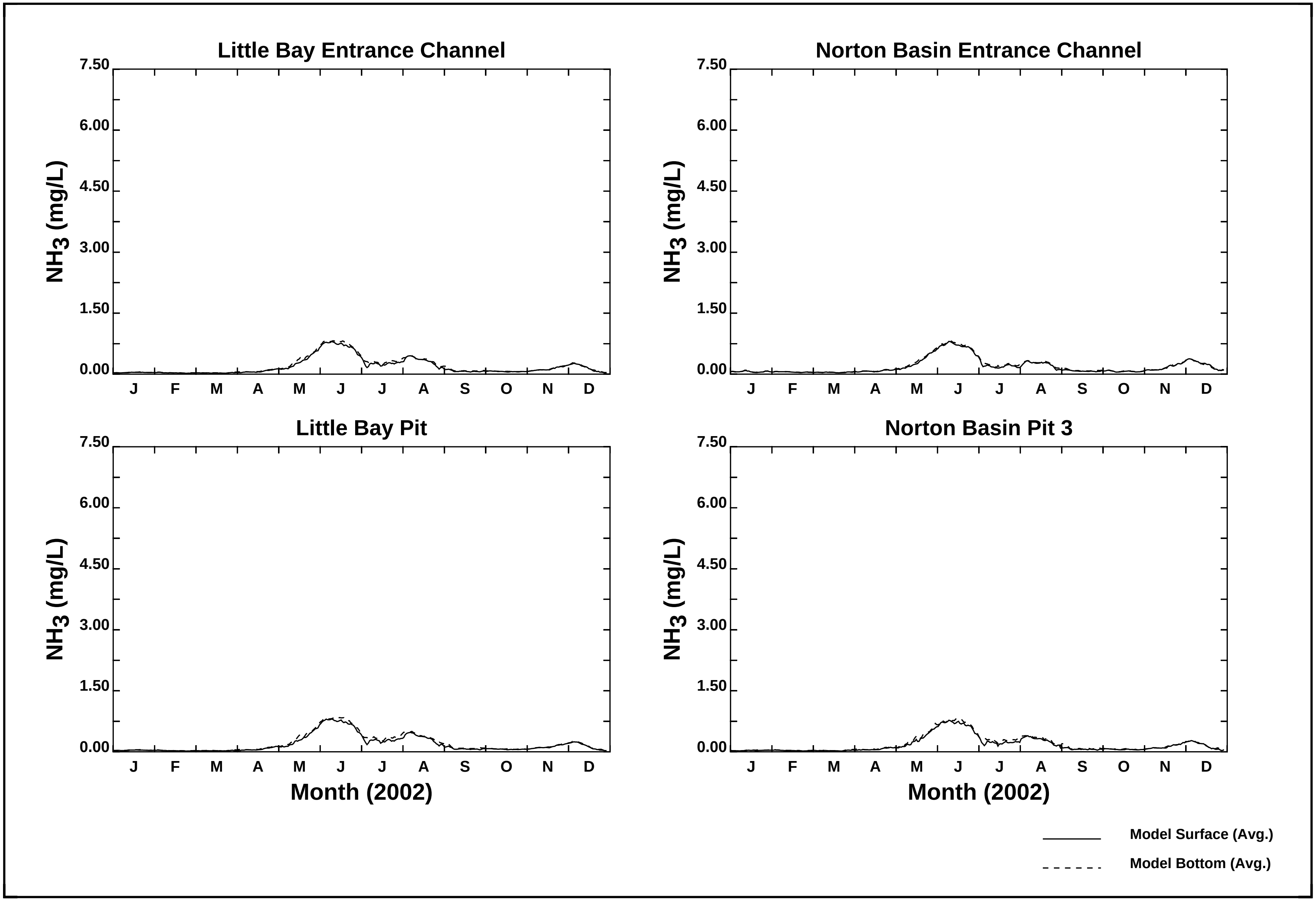



Figure 3-15. - Ammonia (mg/L)
Recontour Norton Basin and Little Bay to 4 m below MSL

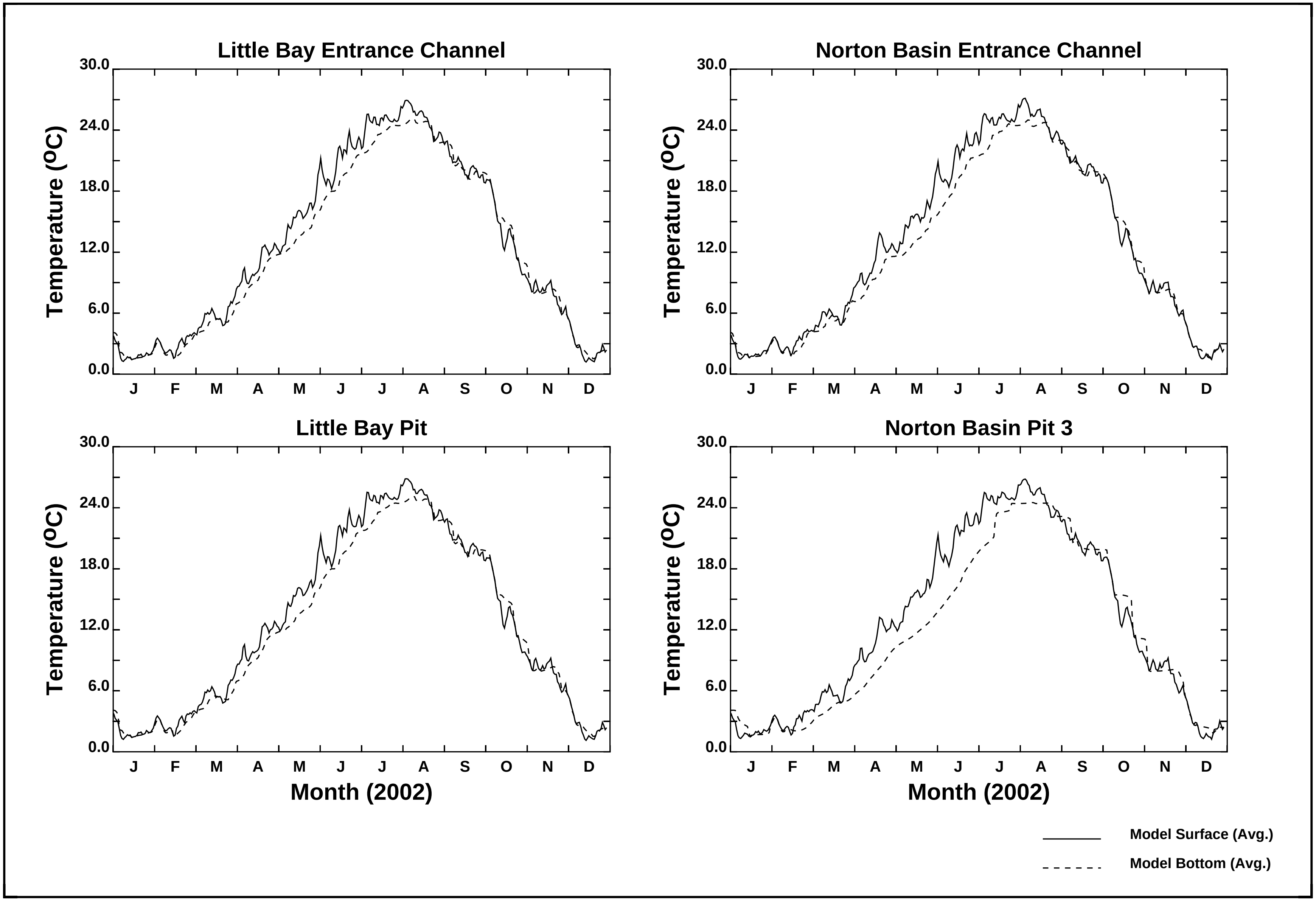



Figure 3-16. - Temperature ($^{O}$C)
Recontour Little Bay to 8 m below MSL

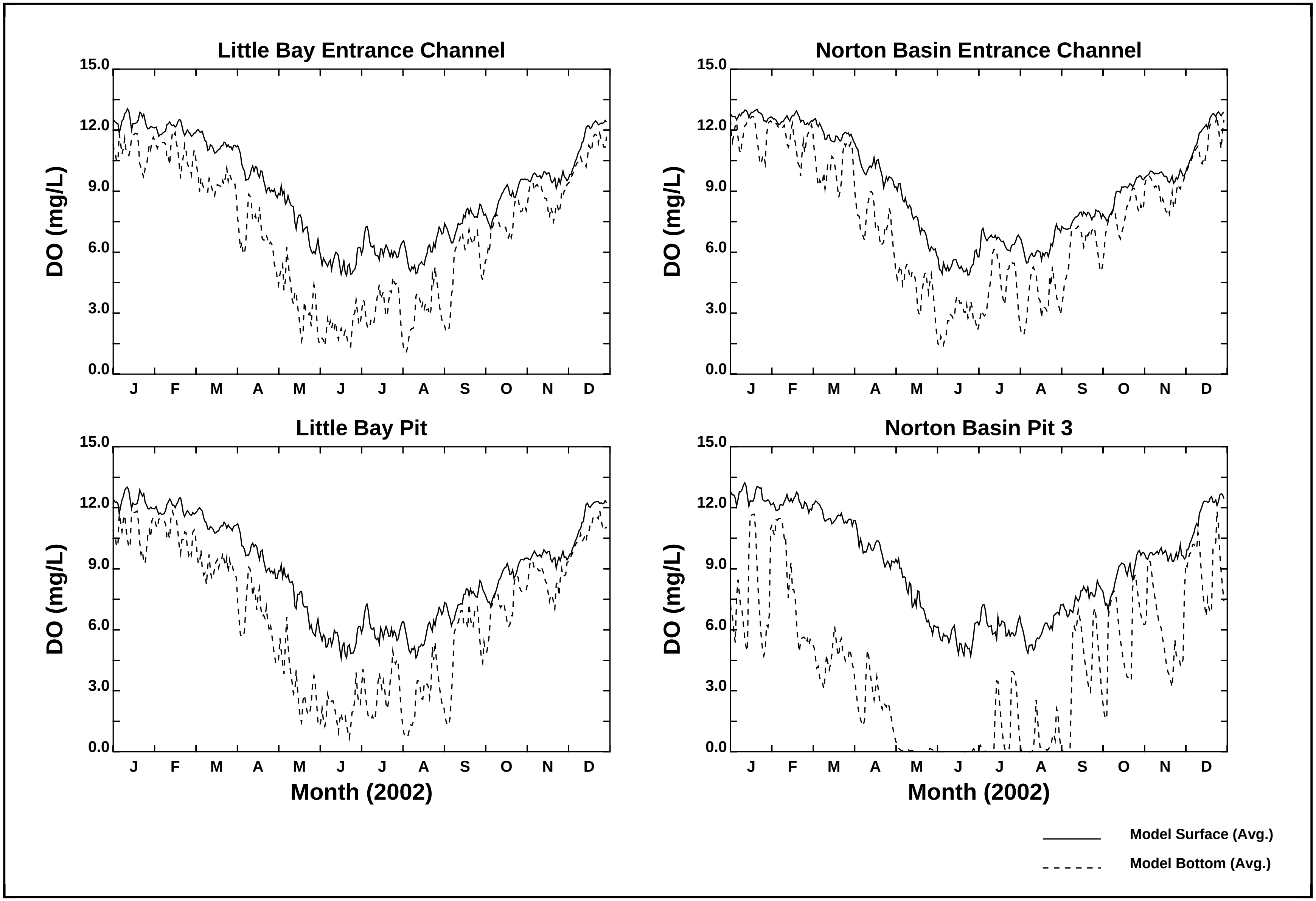



Figure 3-17. - Dissolved Oxygen (mg/L)
Recontour Little Bay to 8 m below MSL

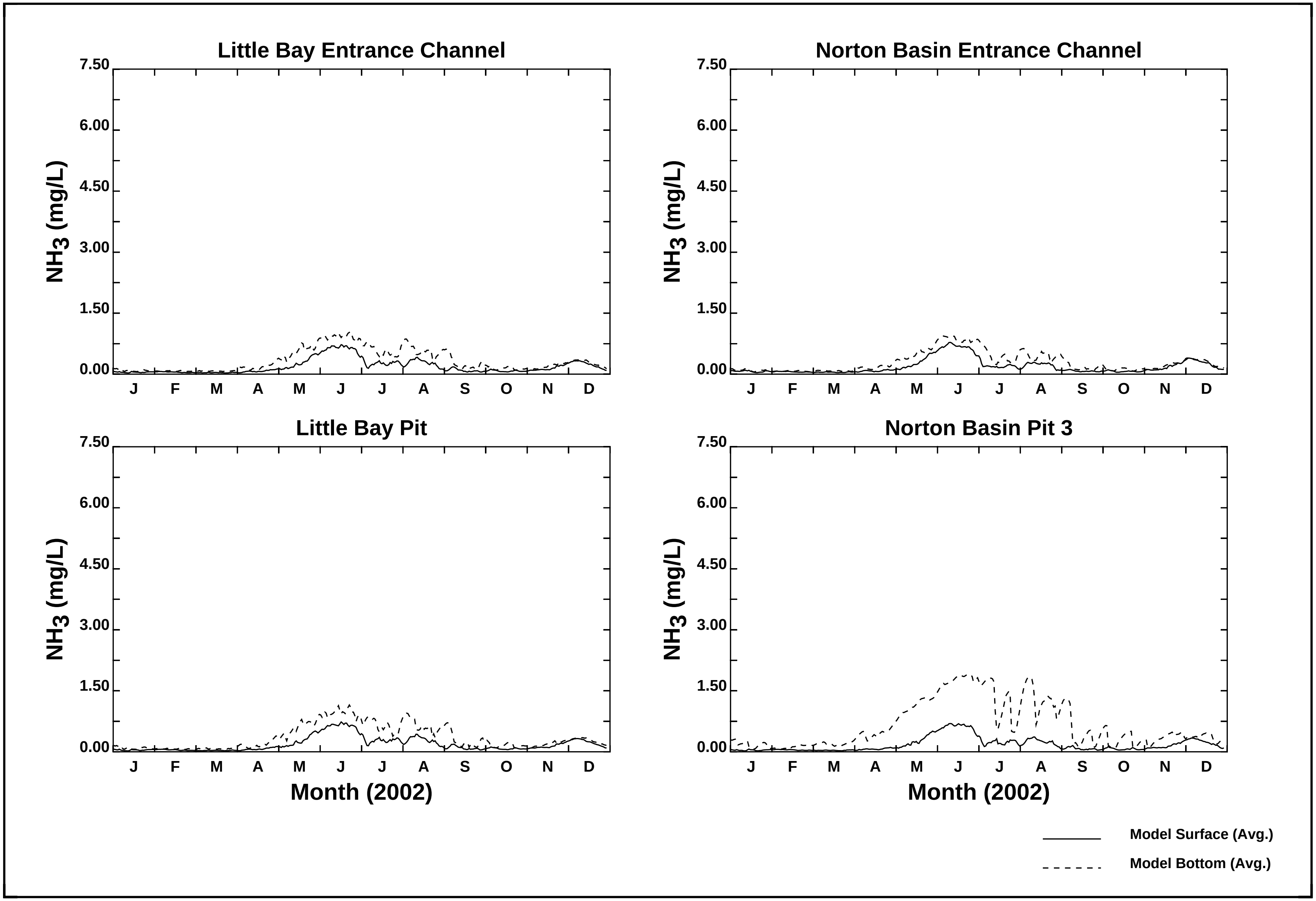



Figure 3-18. - Ammonia (mg/L)
Recontour Little Bay to 8 m below MSL

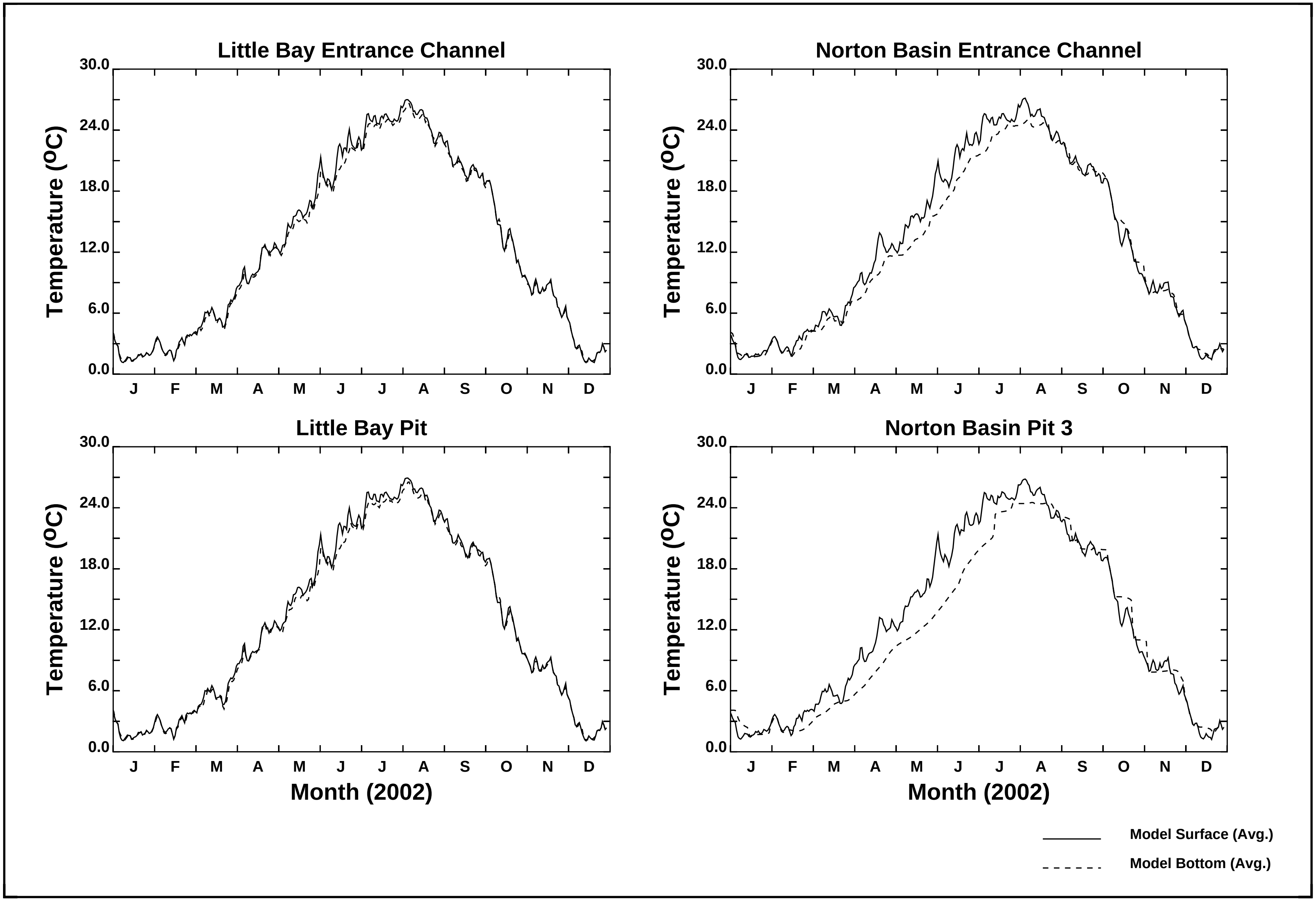



Figure 3-19. - Temperature ($^{O}$C)
Recontour Little Bay to 4 m below MSL

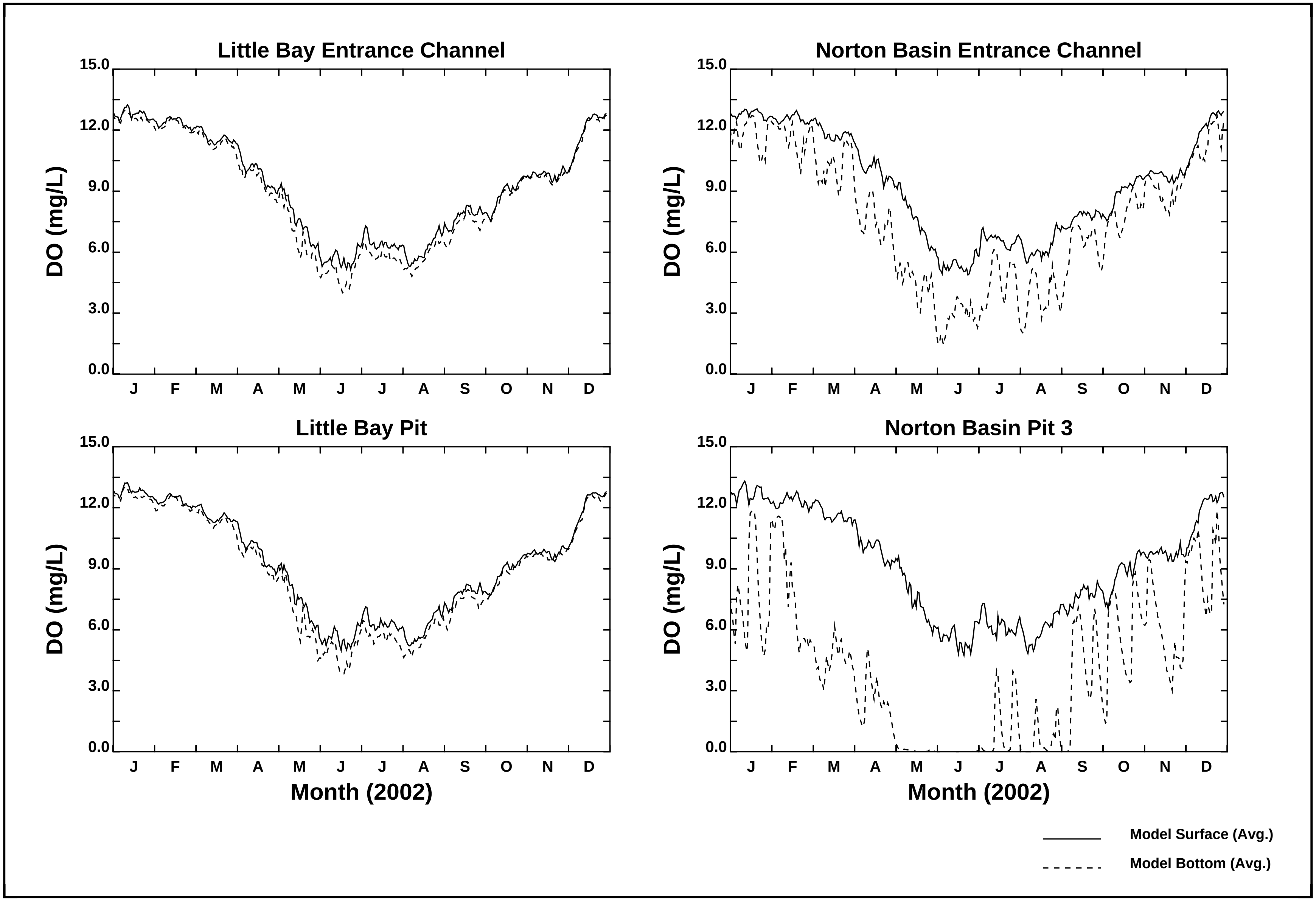



Figure 3-20. - Dissolved Oxygen (mg/L)
Recontour Little Bay to 4 m below MSL

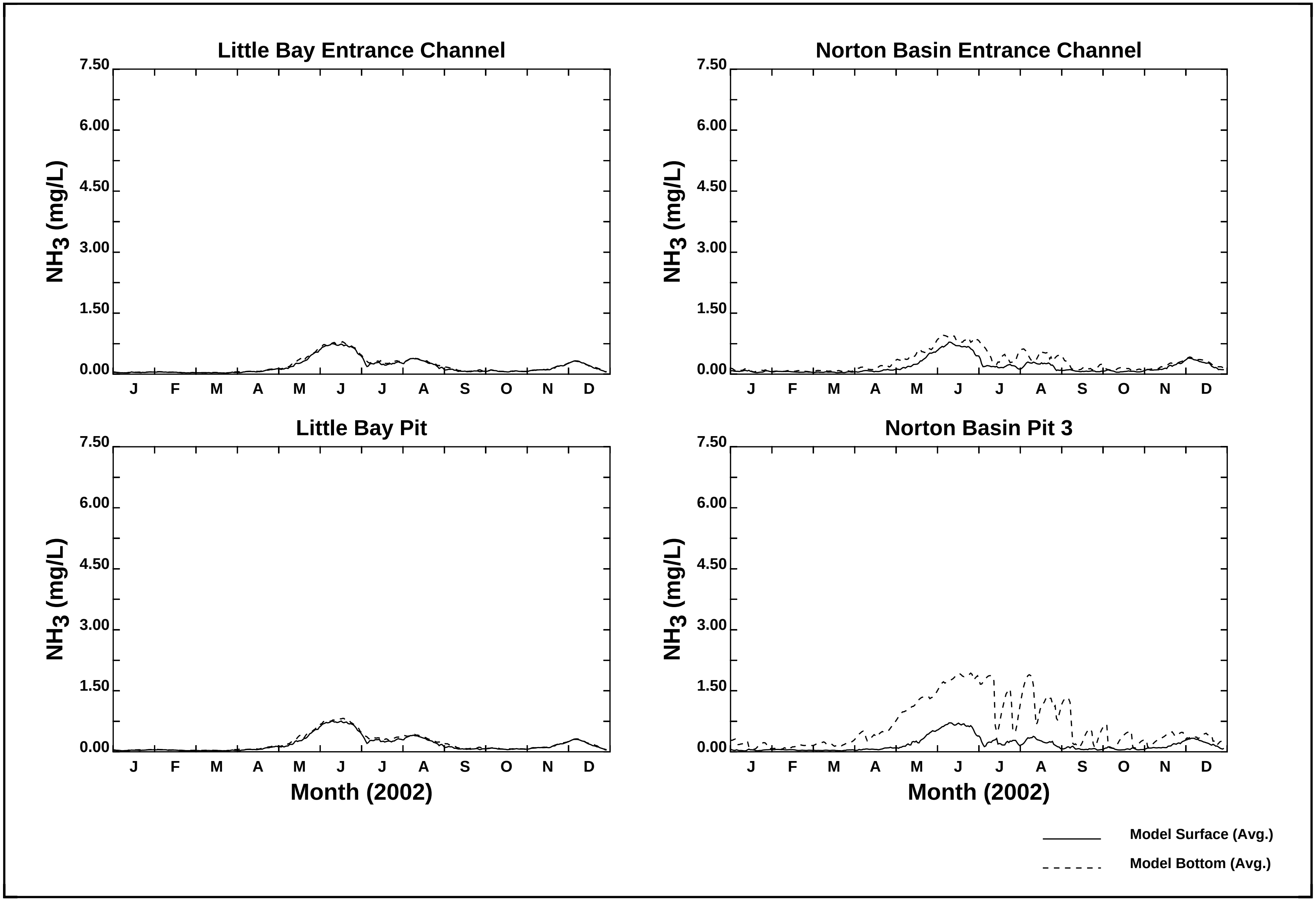



Figure 3-21. - Ammonia (mg/L)
Recontour Little Bay to 4 m below MSL

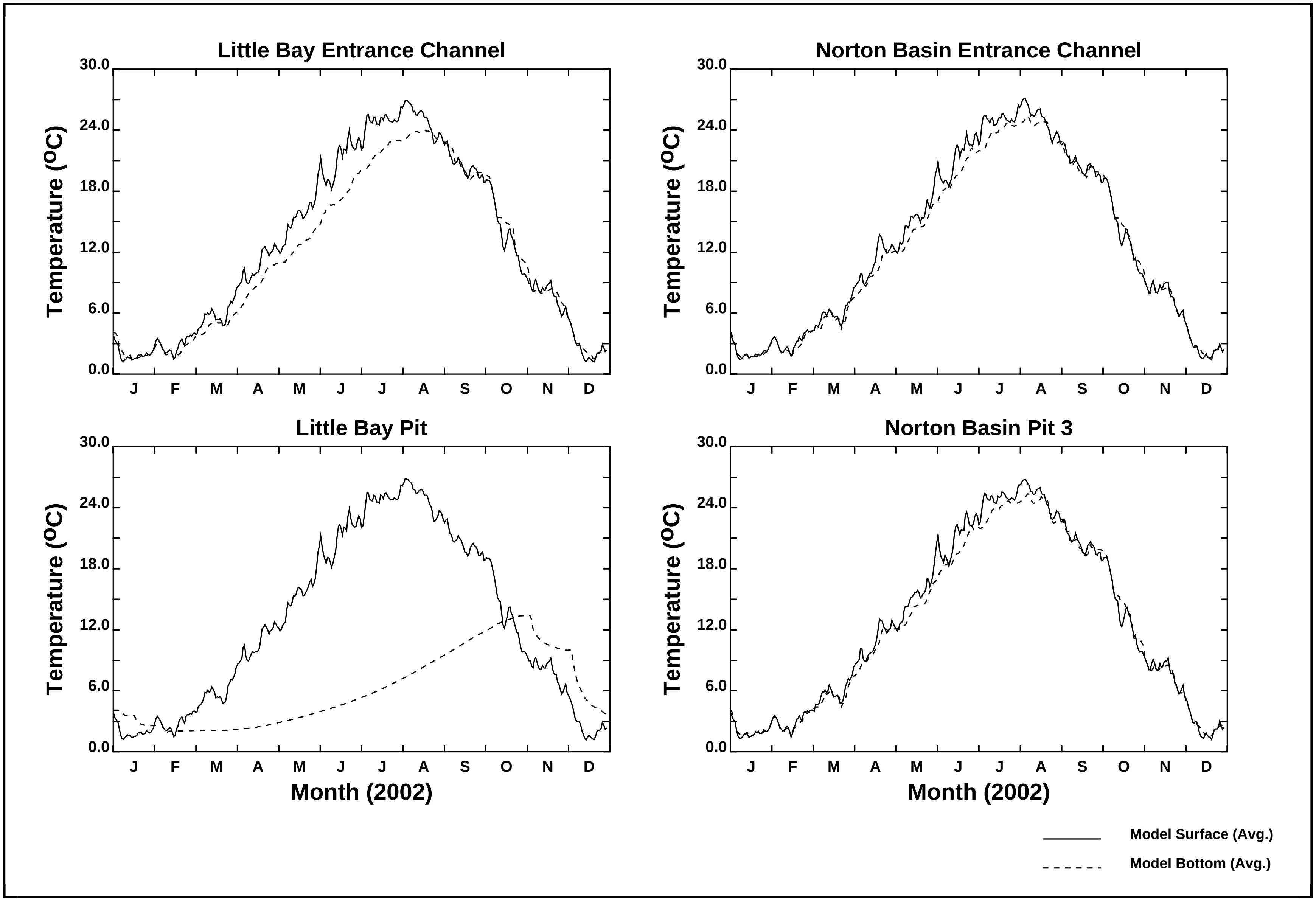



Figure 3-22. - Temperature ($^{o}$C)
Recontour Norton Basin to 8 m below MSL

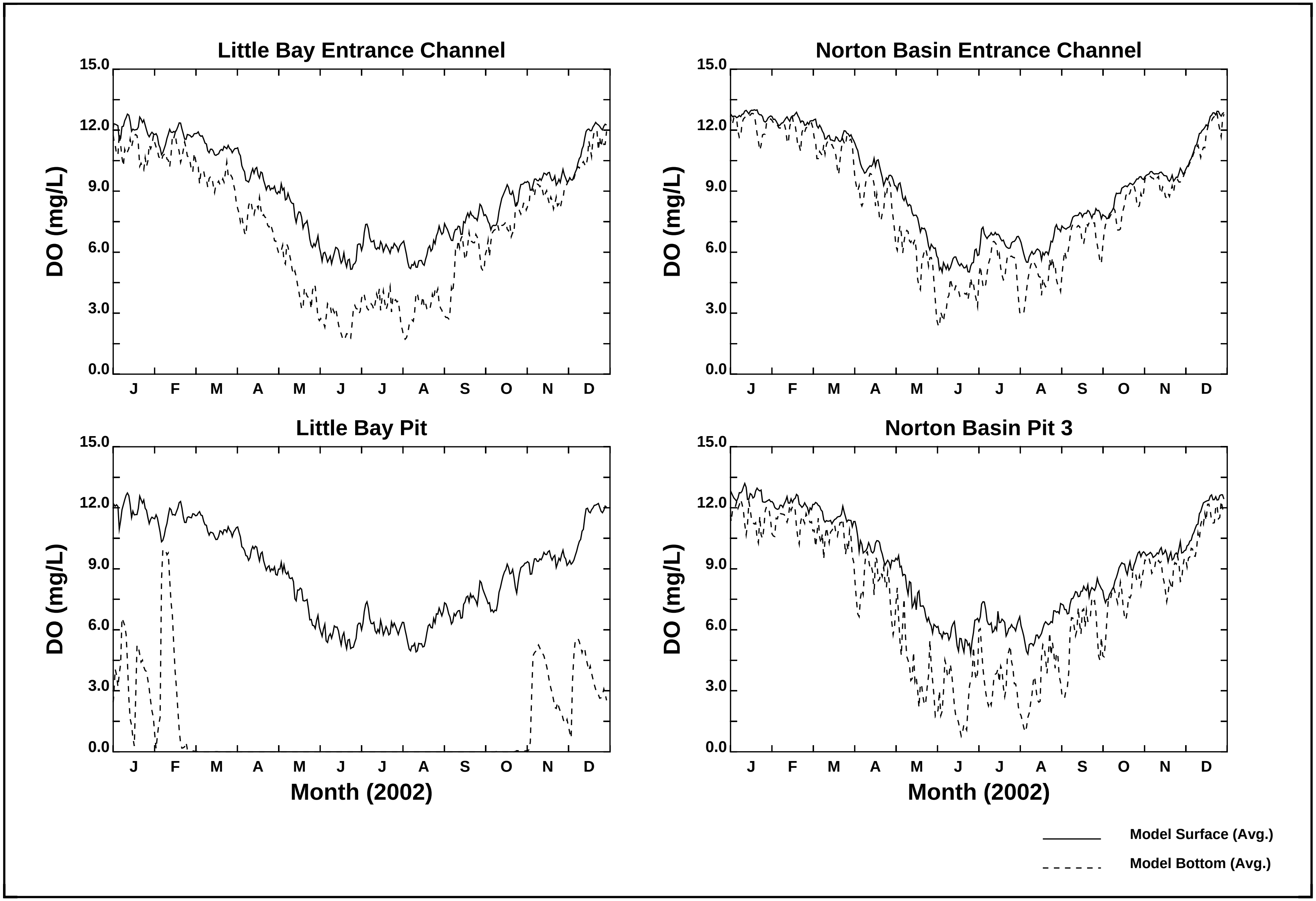



Figure 3-23. - Dissolved Oxygen (mg/L)
Recontour Norton Basin to 8 m below MSL

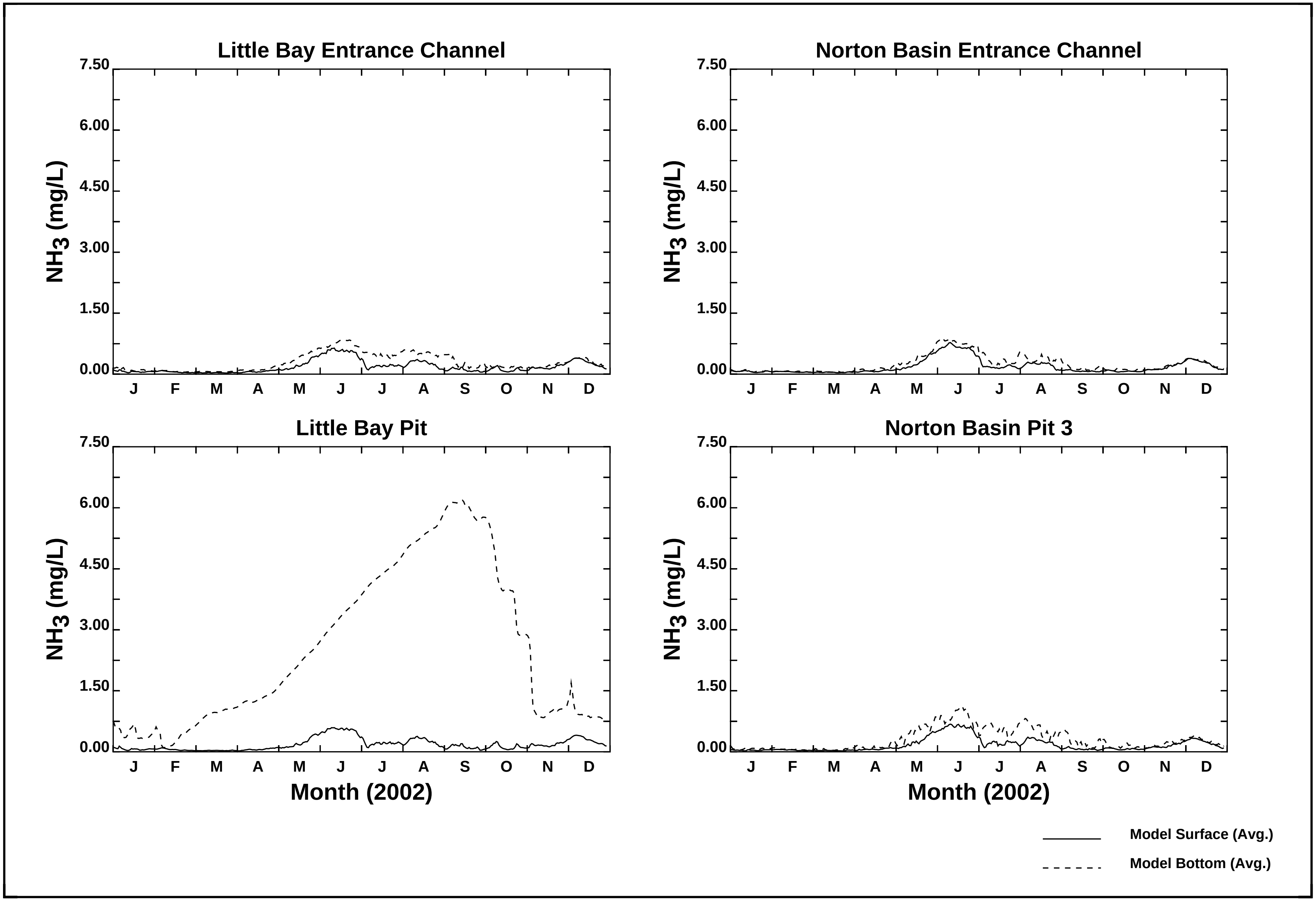



Figure 3-24. - Ammonia (mg/L)
Recontour Norton Basin to 8 m below MSL

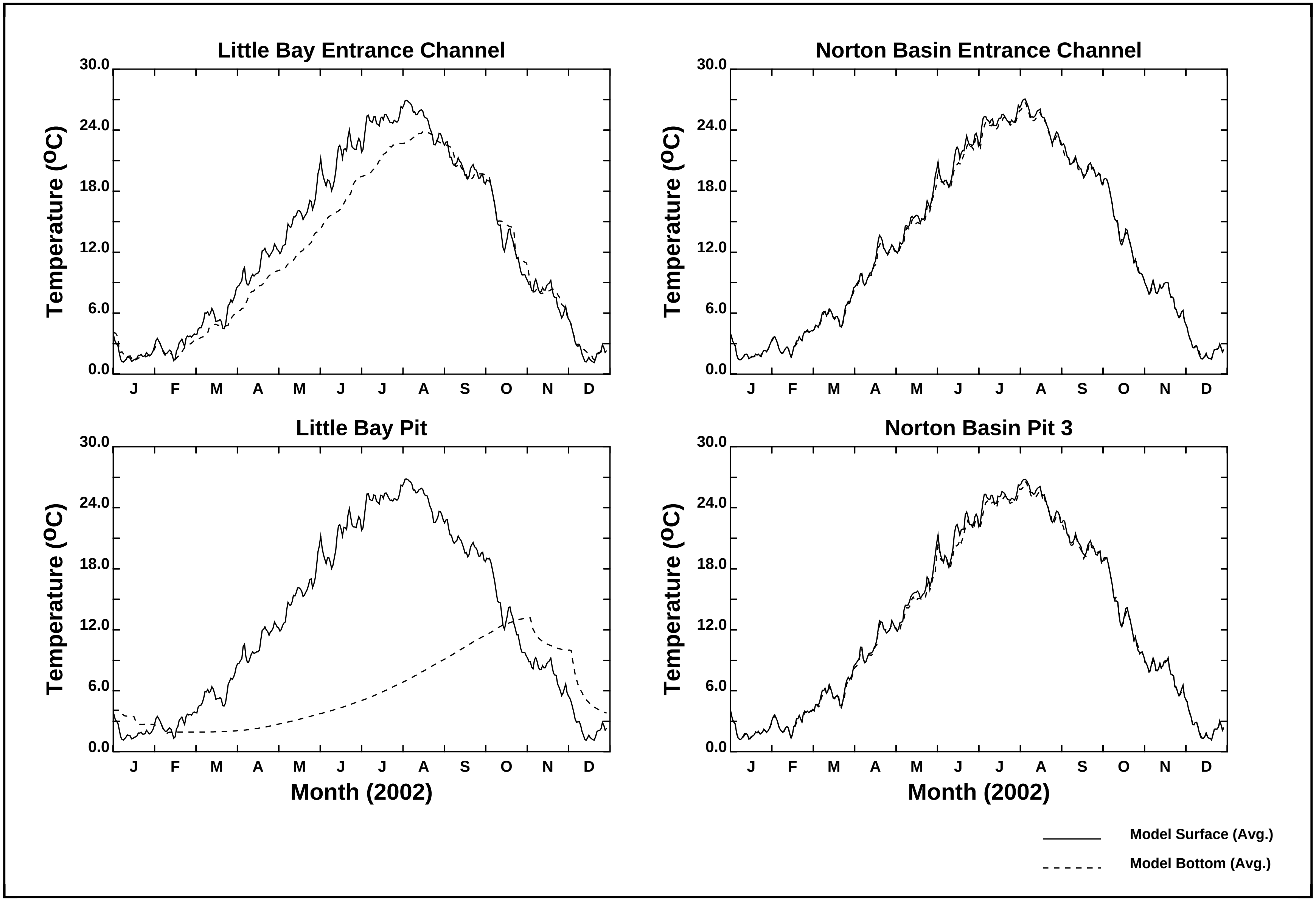



Figure 3-25. - Temperature ($^{O}$C)
Recontour Norton Basin to 4 m below MSL

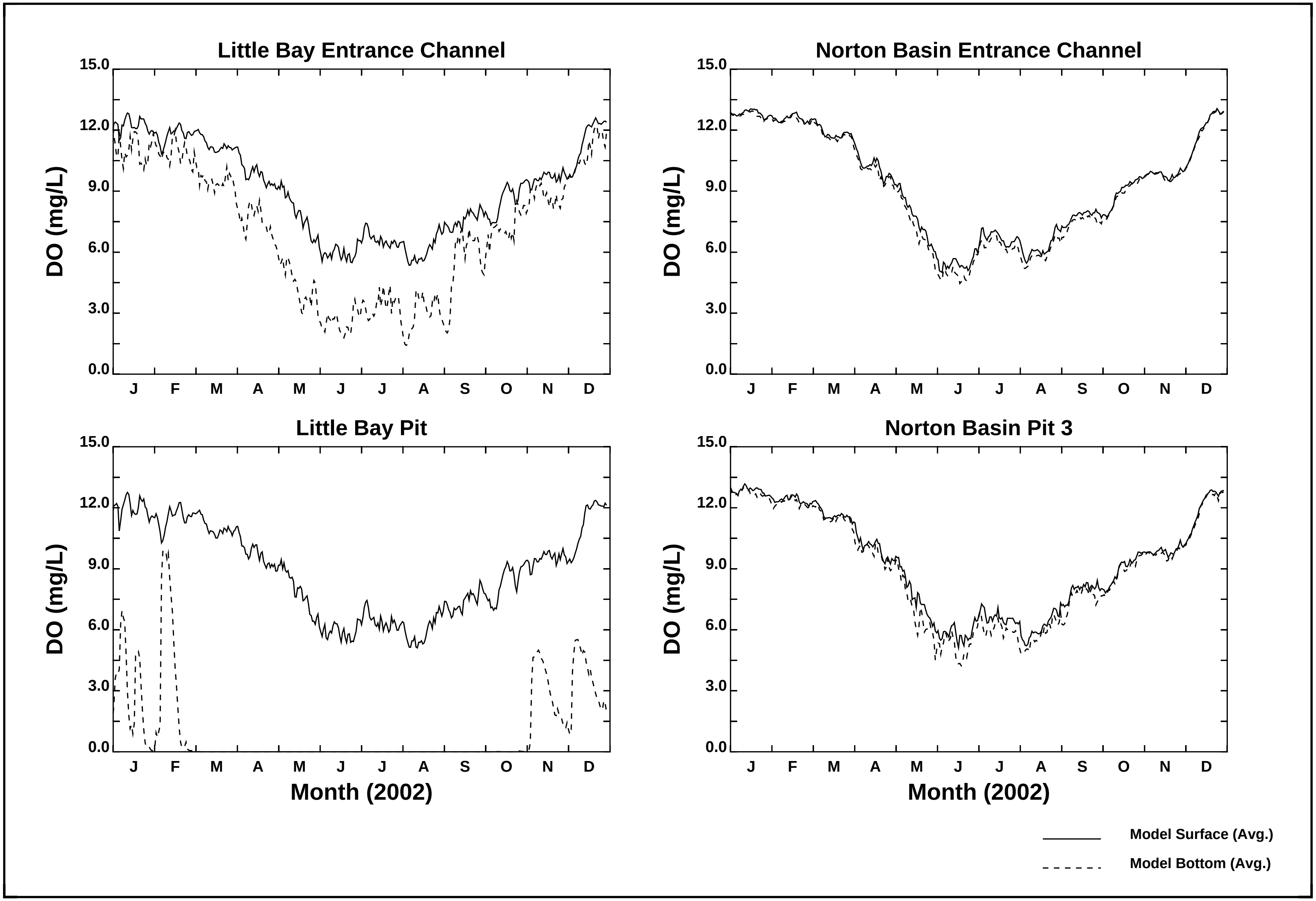



Figure 3-26. - Dissolved Oxygen (mg/L)
Recontour Norton Basin to 4 m below MSL

Norton Basin, and there are only a few periods when the DO concentration is calculated below 5.0 mg/L. Figure 3-27 shows that ammonia concentrations in Norton Basin decline.

Slightly more temperature stratification occurs in Little Bay as the bay becomes even more cutoff from Norton Basin. Bottom water DO concentrations in Little Bay are slightly lower, and bottom ammonia concentrations remain high.

Recontour Norton Basin and Little Bay with a slope from 4 m to 6 m

It is not likely that Norton Basin and Little Bay will be recontoured with a constant depth. This scenario crudely analyzes the impact of a sloped bathymetry on water quality. The Z-level model that was used limited depths to 2 m increments. As can be observed in Figures 3-28, 3-29 and 3-30. The results of this scenario are nearly identical to recontouring Norton Basin and Little Bay to 4 m below MSL. Water quality improves significantly under the conditions of this scenario as compared to existing conditions. No benefit to water quality will be lost if the bathymetry is made to slope towards the mouth from the head ends of the basins.

Recontour Norton Basin and Little Bay with a slope of 3 m to 6 m below MSL

One sensitivity was run using one-meter depth increments rather than two-meter depth increments to improve the analysis of a sloped bathymetry. This alternative results in significantly improved water quality over the baseline conditions. Figure 3-31 shows that the temperature stratification is removed under these conditions. However, the dissolved oxygen concentrations are not as high as the recontour to 4 m below MSL scenario. The DO concentrations in Figure 3-32 do remain above 3.0 mg/L. Ammonia concentrations, presented in Figure 3-33, are reduced to background levels.

Shear Stress Analysis

A shear stress analysis was completed for the dredged channel scenario and the scenario with the most recontouring, the recontouring both basins to 4 m below MSL scenario. The greatest amount of recontouring should result in the largest shear stresses. The analysis was completed for the entire 2002 period. As a general rule, a shear stress of greater than 1.0 dyne/cm$^2$ will begin to resuspend cohesive sediments.

Figure 3-34 presents the results of the dredged channel scenario. The model computes shear stresses in the entrance channel that are high enough to resuspend material. It is likely that the channel would remain sandy without much sedimentation of organic materials. The borrow pits in both Norton Basin and Little Bay have extremely low calculated shear stresses. Under the dredged channel scenario conditions the borrow pits would continue to accumulate clays, silts and organic material.

The shear stress modeling results for filling the borrow pits to 4.0 m below MSL are presented in Figure 3-35. Under these conditions the northern portion of the entrance channel continues to have shear stresses that would cause the resuspension of material. In the southern portion of the entrance channel, the shear stresses are reduced by approximately one half. In Pit 3 of Norton Basin (note scale change), the shear stresses increase substantially, but remain below 1.0 dyne/cm$^2$. At the head ends of the basins, the filled pits are calculated to have increased shear stresses, as well. However, these shear stresses are small, less than 0.2 dyne/cm$^2$. The modeling results show very little shear stress at the former borrow pit sites. These results indicate that it is highly unlikely that material used to recontour these basins would be resuspended under the vast majority of meteorological and tidal conditions.

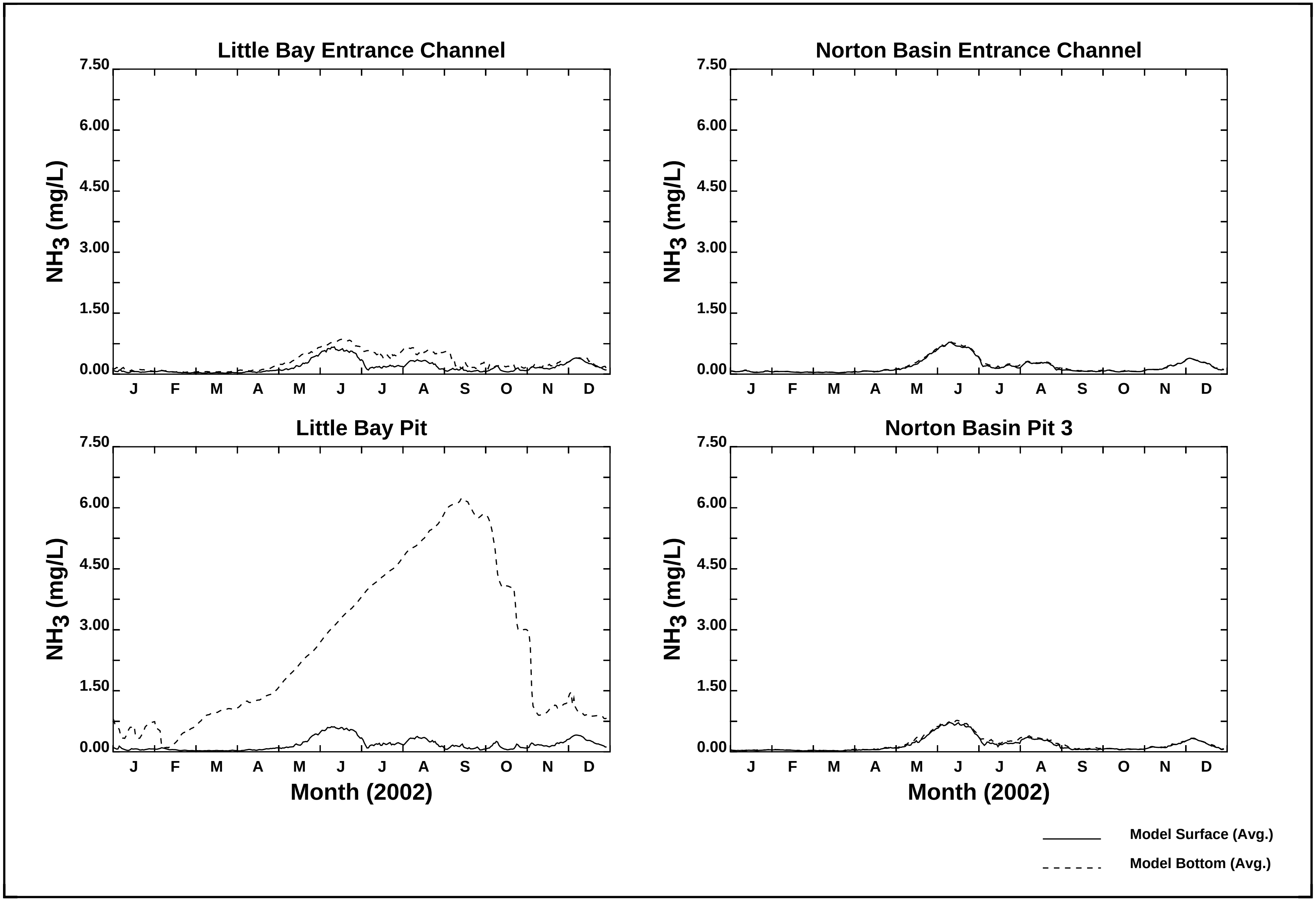



Figure 3-27. - Ammonia (mg/L)
Recontour Norton Basin to 4 m below MSL

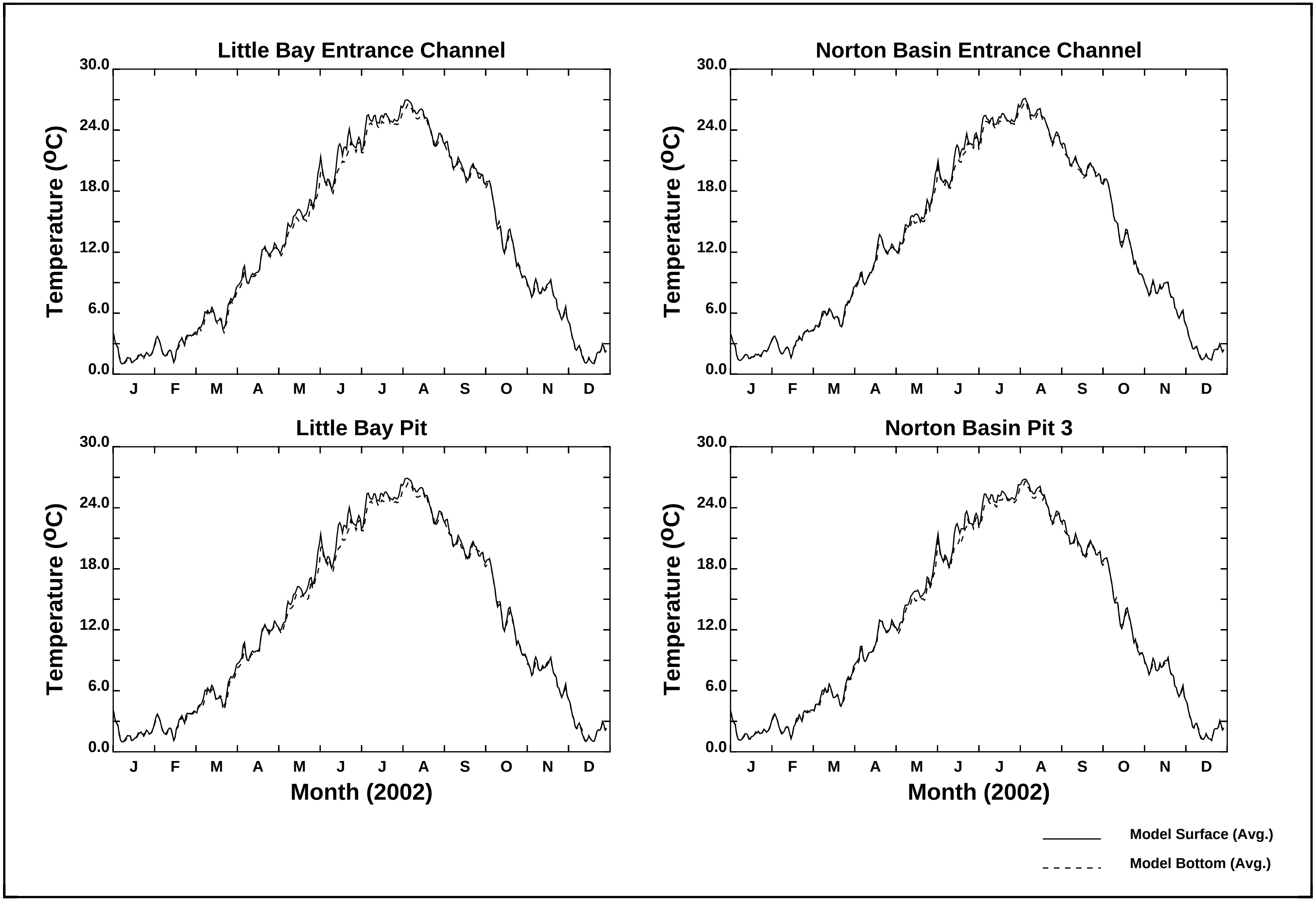



Figure 3-28. - Temperature ($^{O}$C)
Sloping Recontour of Norton Basin and Little Bay from 4 m to 6 m below MSL

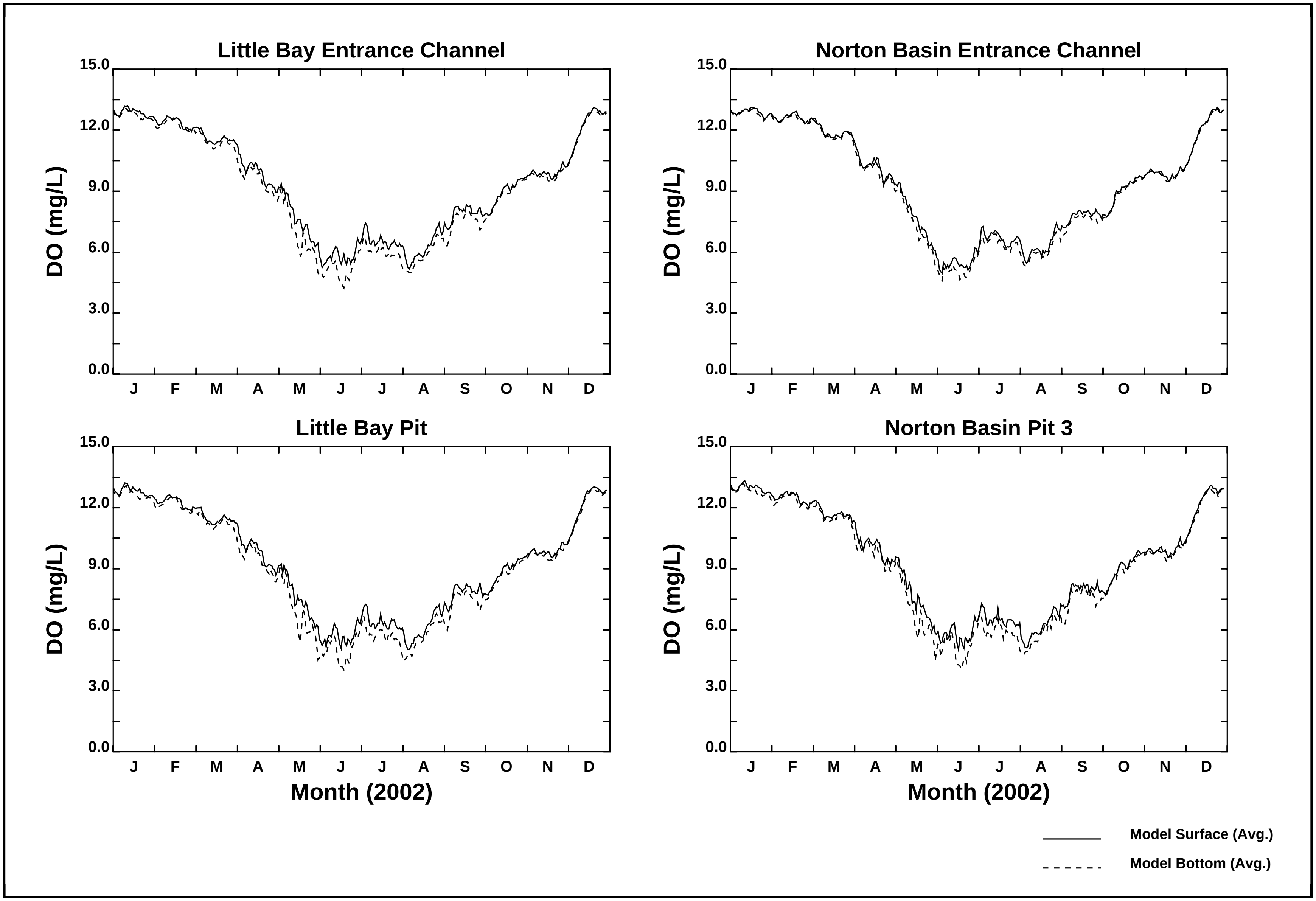



Figure 3-29. - Dissolved Oxygen (mg/L)
Sloping Recontour of Norton Basin and Little Bay from 4 m to 6 m below MSL

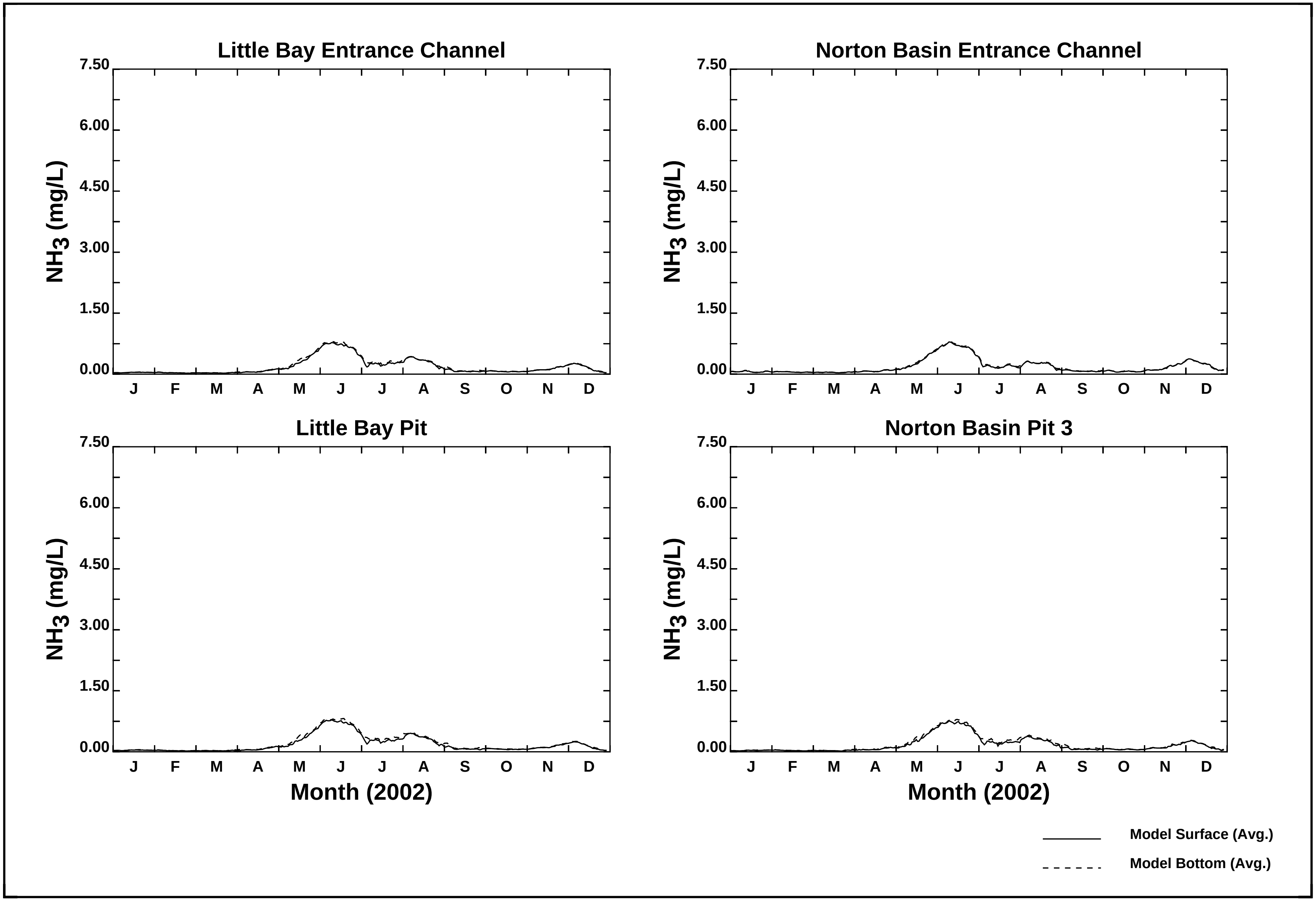



Figure 3-30. - Ammonia (mg/L)
Sloping Recontour of Norton Basin and Little Bay from 4 m to 6 m below MSL

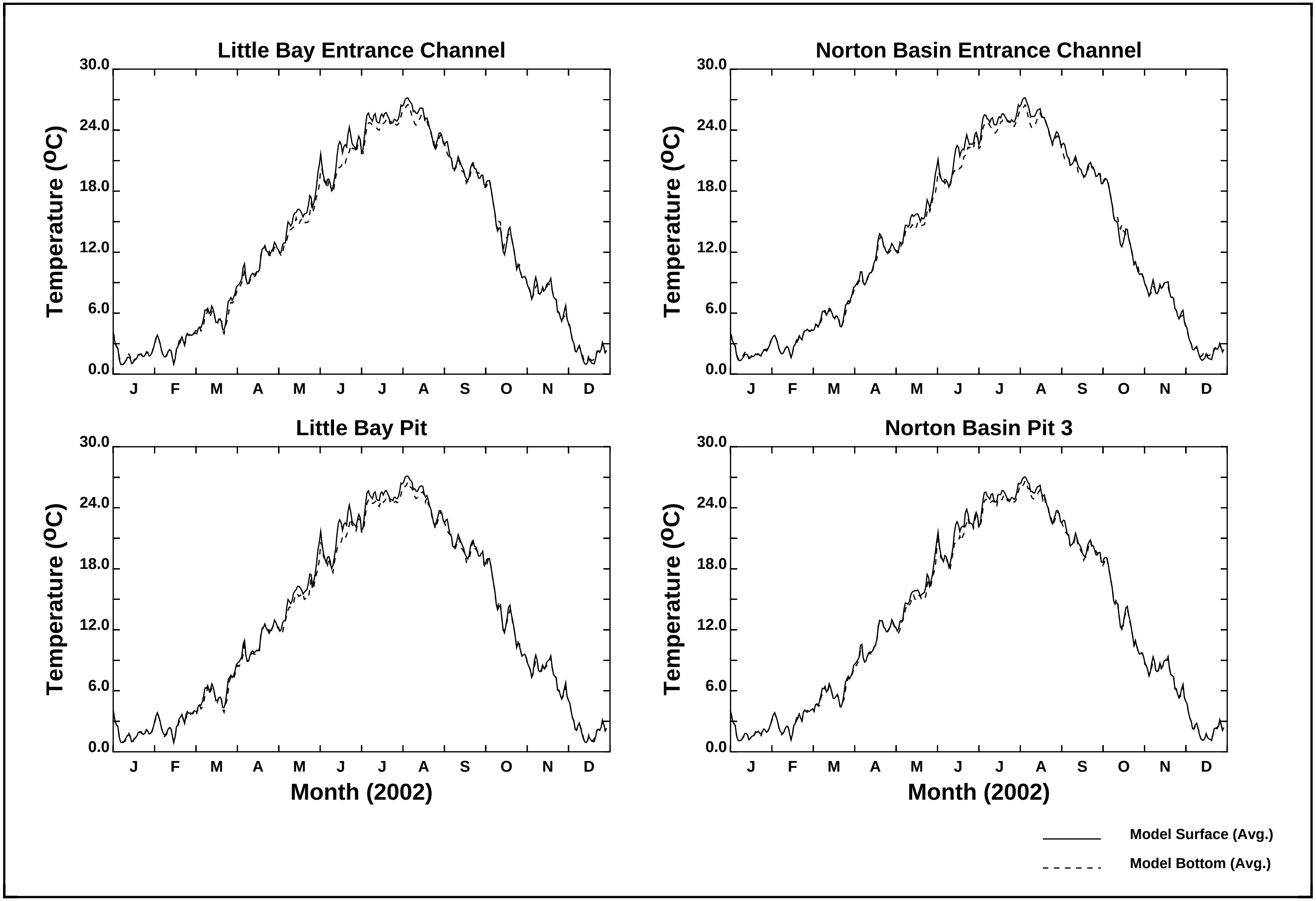



Figure 3-31. - Temperature ($^{O}$C)

Sloping Recontour of Norton Basin and Little Bay from 3 m to 6 m below MSL (1 m)

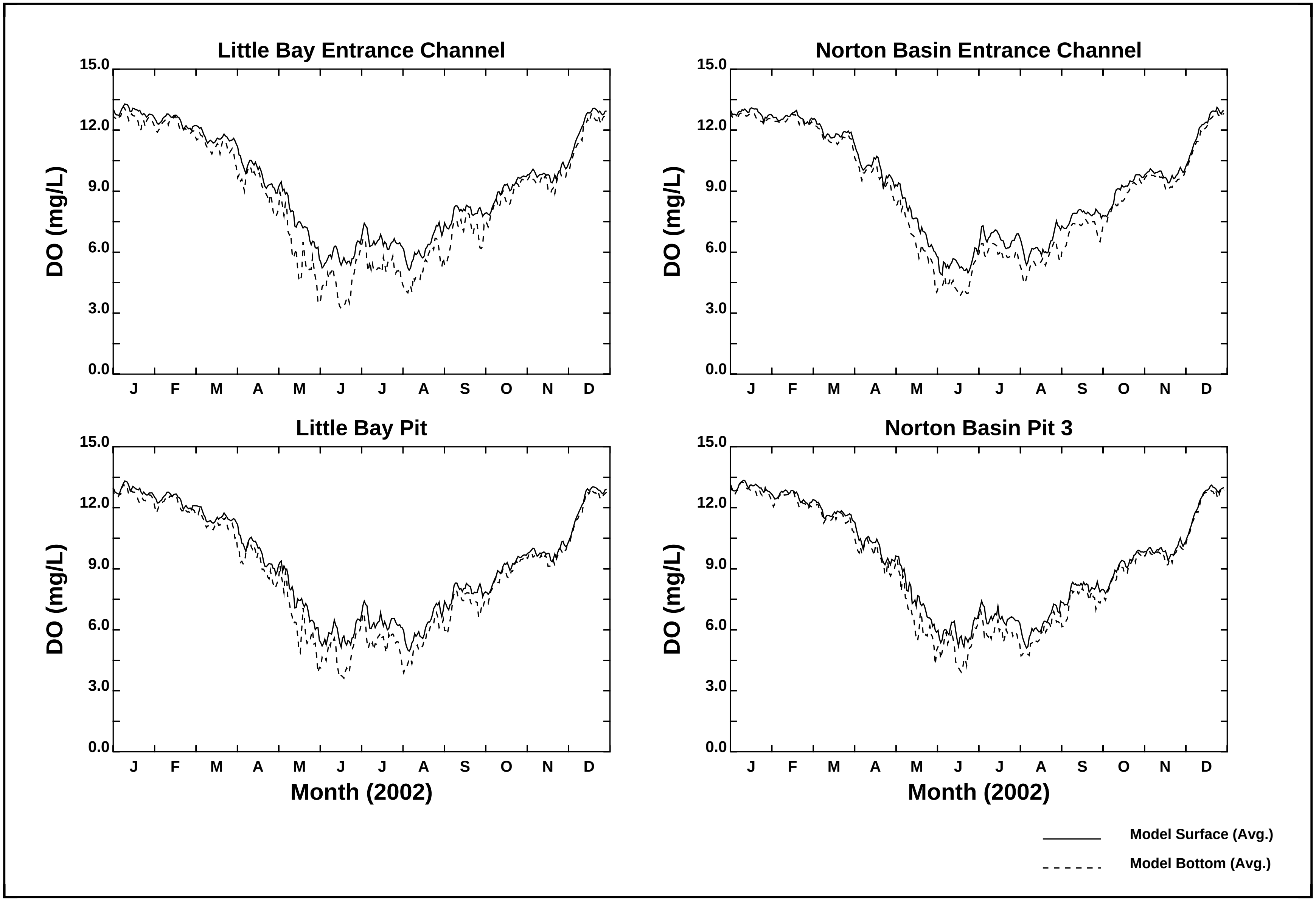



Figure 3-32. - Dissolved Oxygen (mg/L)
Sloping Recontour of Norton Basin and Little Bay from 3 m to 6 m below MSL (1 m)

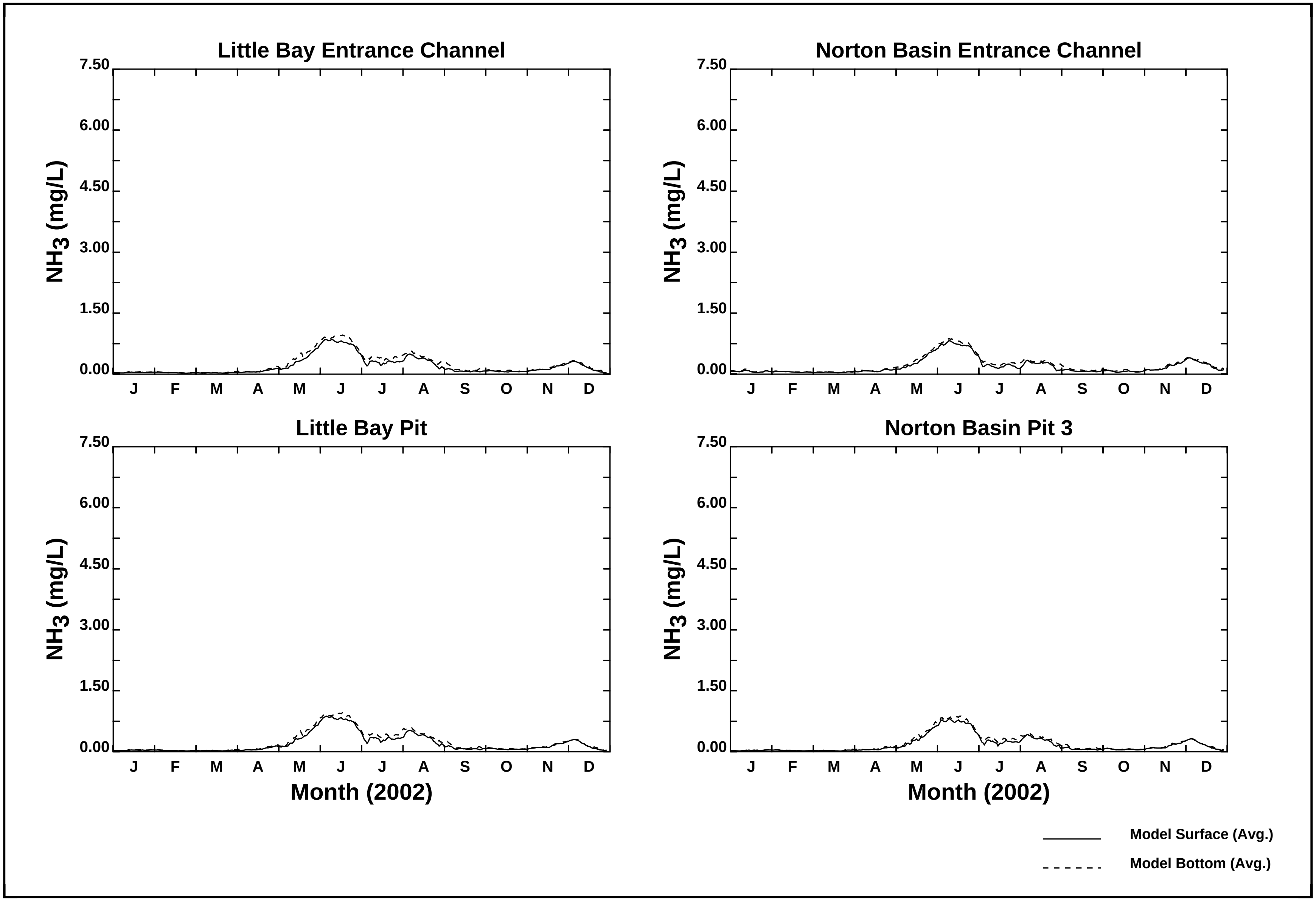



Figure 3-33. - Ammonia (mg/L)
Sloping Recontour of Norton Basin and Little Bay from 3 m to 6 m below MSL (1 m)

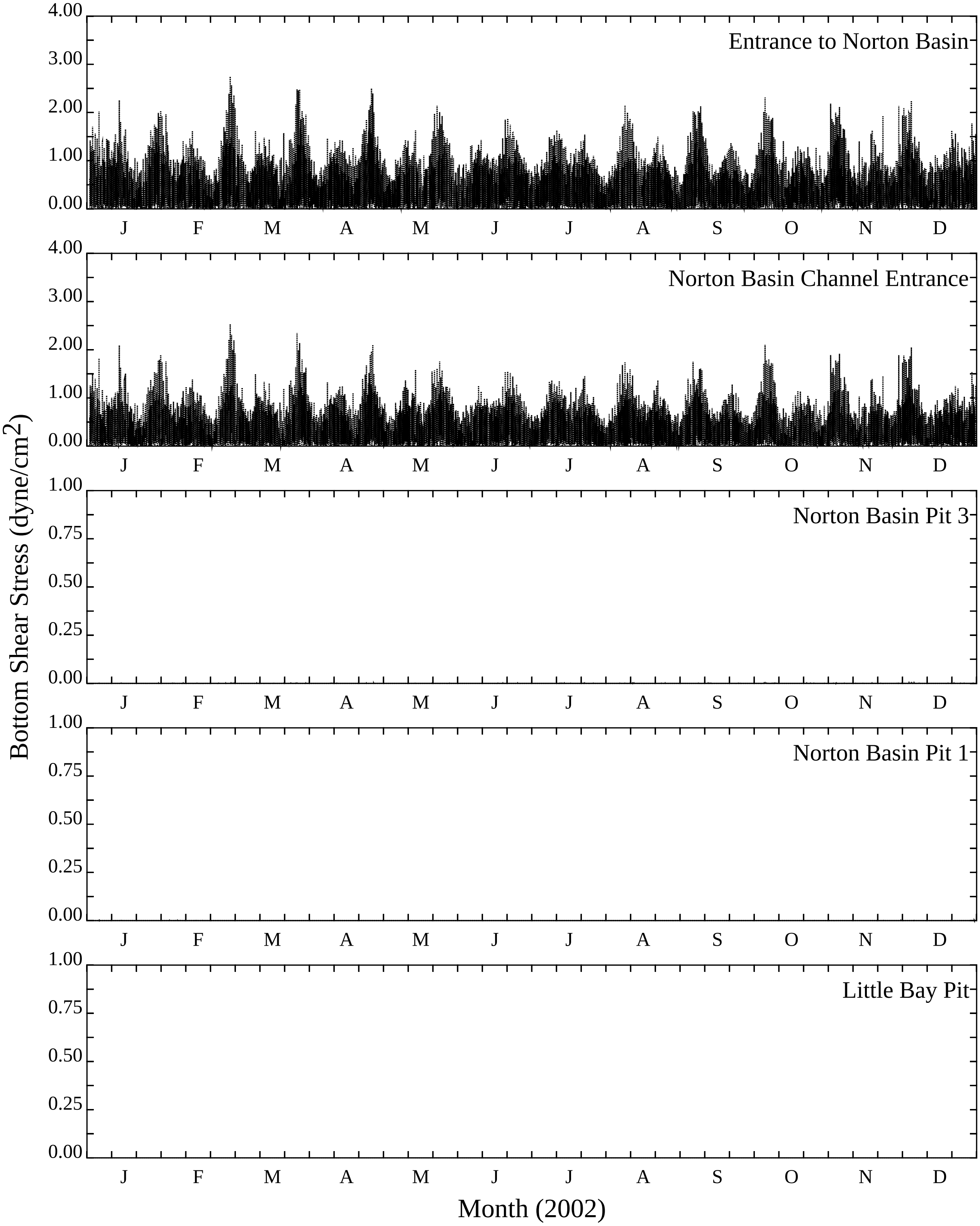



Figure 3-34. Shear Stress Calculation for Dredged Channel Scenario

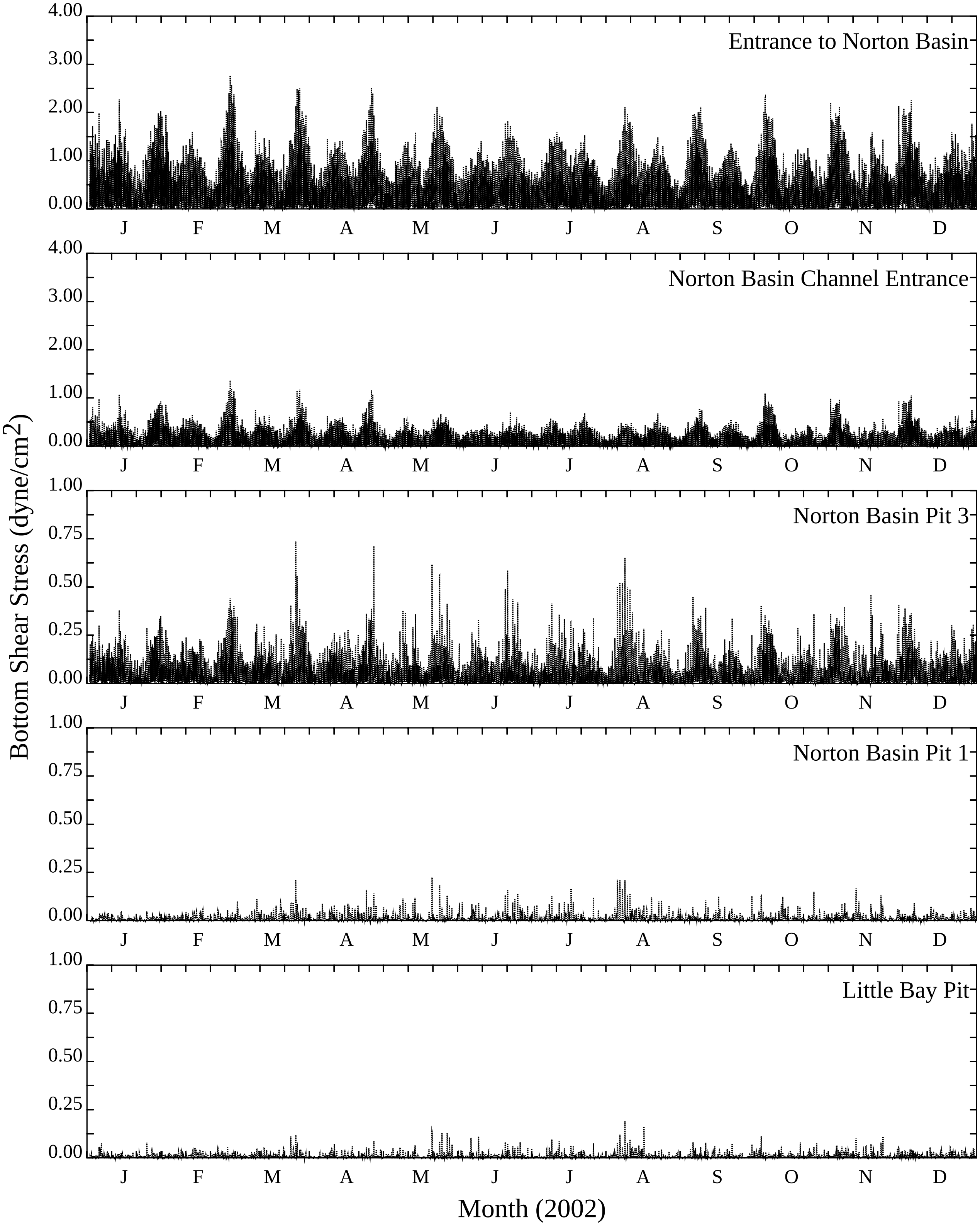



Figure 3-35. Shear Stress Calculation for Recontour Norton Basin and Little Bay to 4 m Scenario

# SECTION 4

# DISCUSSION

Jamaica Bay is a eutrophic waterbody. The nitrogen loads into the bay are large enough to impact the entire bay even if parts of the bay are not close to a large nitrogen source. These high nitrogen levels result in the growth of phytoplankton and *Ulva*. When these algae enter a dead-end basin, especially those that have been artificially deepened, the stagnant conditions allow the algae to settle to the bottom sediments. Deep pits tend to accumulate this organic material. As this material is broken down, a sediment oxygen demand is created that removes oxygen from the water column. The stagnant water in these deep pits allows temperature stratification to set up that prevents vertical mixing. Due to the temperature stratification, water reaerated at the surface by the atmosphere cannot mix into the deeper waters to replenish the oxygen that has been used as part of the organic matter decomposition process. The result is low dissolved oxygen (hypoxia) or the lack of oxygen (anoxia) in the bottom waters. Sediment processes also produce hydrogen sulfide and ammonia that accumulates in the bottom waters. All of these factors contribute to highly inhospitable conditions for most aquatic life.

The keys to improving the habitat in Norton Basin and Little Bay are the reduction of nutrients in the water column and the elimination of vertical density stratification. The shallower the basins are made, the easier it is for the water column to mix. However, if the basins are made too shallow, undesirable *Ulva* may take over the newly recontroured areas if there is enough available light for *Ulva* growth.

The reduction of nitrogen loading to the bay is being examined as part of the NYCDEP's Comprehensive Jamaica Bay Water Quality Plan for nitrogen. The USACE's ecosystem restoration work will improve vertical mixing through the recontouring of Norton Basin and Little Bay. Modeling conducted as part of this study has shown that recontouring to a depth of 8 m below MSL would improve dissolved oxygen levels in the deep borrow pits, and most likely eliminate ammonia toxicity in these basins. Recontouring to a depth of 4 m below MSL would eliminate vertical stratification and increase dissolved oxygen even further. Recontouring to a depth of 6 m produces results between the 8 m and 4 m conditions.

Existing water quality data seems to confirm that shallower areas have better water quality than deeper areas. Shallow areas in Norton Basin have been shown to have fairly good water quality (BVA, 2005b). Around Jamaica Bay there are numerous tributaries and basins. Many have been artificially deepened, or have large inputs from CSOs. These basins generally suffer from poor water quality. One tributary that has fairly good water quality is Spring Creek. Not surprisingly, Spring Creek is relatively shallow.

Based on the available data and modeling analysis, recontouring Norton Basin and Little Bay should have a positive effect on water quality and should improve habitat in these currently degraded waterbodies.

# SECTION 5

# CONCLUSIONS AND RECOMMENDATIONS

From a purely scientific and engineering standpoint, recontouring Norton Basin and Little Bay to depths of 4 m below MSL produces the most improvement in water quality conditions and the highest bottom water dissolved oxygen levels. Water quality in the shallow areas of Norton Basin and Little Bay already appear to be fairly good. Recontouring the borrow pits should improve water quality so that it is similar to the existing shallow areas. When recontouring occurs, care should be taken not to produce pits or depressions in the bottom sediments where organic material can accumulate. A gentle slope, shallower at the head end and deeper near the mouth, should help organic material exit the basins. Modeling shows that under the vast majority of meteorologic and tidal conditions, the bottom sediments would not be resuspended. Hurricane force winds or the affects of a tsunami were not analyzed.

Should recontouring the basins to 4 m below MSL not be a viable alternative, the other recontouring scenarios indicate that some benefit will result even if less material is used in the borrow pits.

Pairing nitrogen reduction at the NYCDEP WPCPs with recontouring Norton Basin and Little Bay would do more to guarantee the stability of DO improvement and improved bottom habitat than recontouring alone.

# SECTION 6

## REFERENCES

Barry A. Vittor and Associates. 2005. Norton Basin/Little Bay Summary Report. Prepared for the New York District, U.S. Army Corps of Engineers.

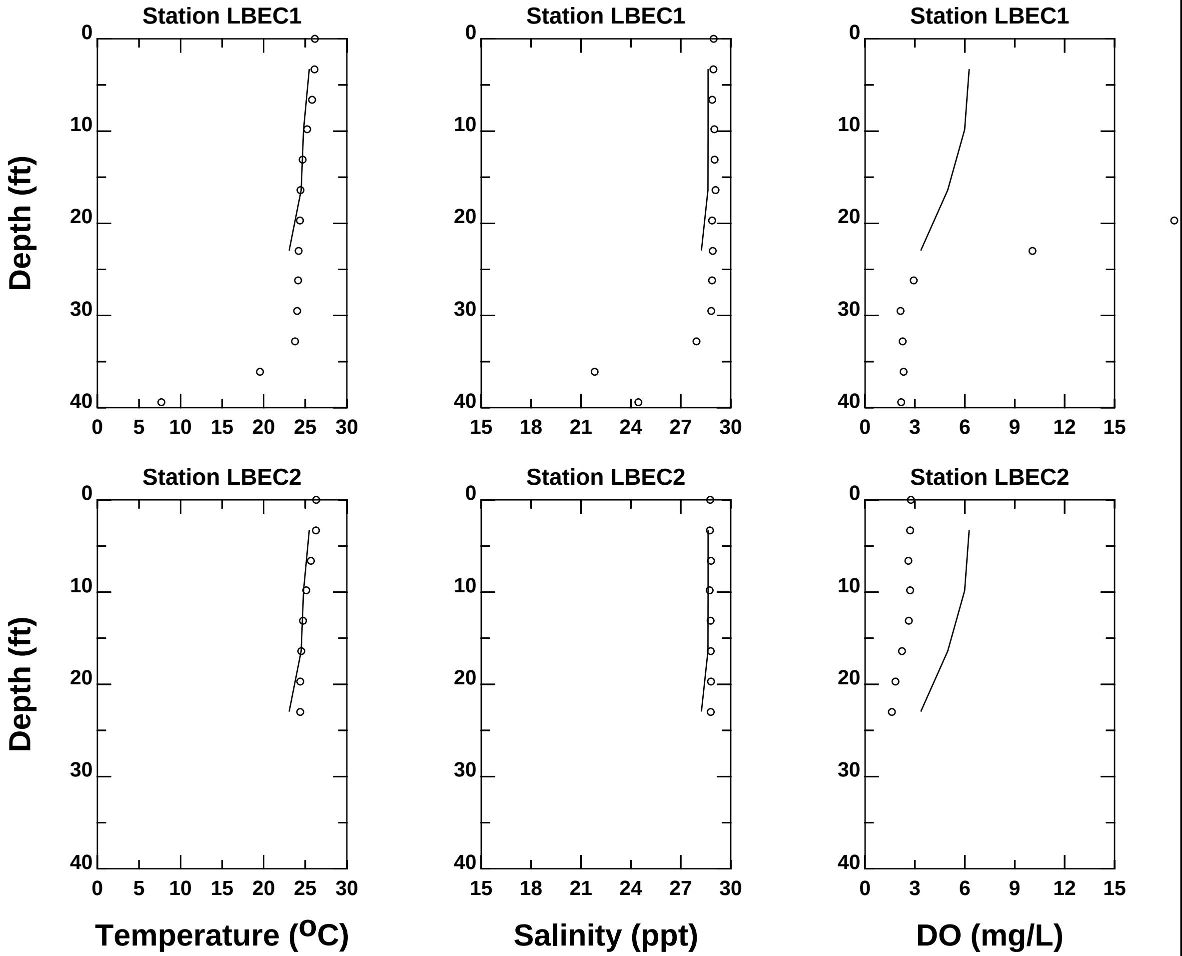
Barry A. Vittor and Associates. 2005b. Norton Basin/Little Bay Technical Summary Report (2000-2003). Prepared for the New York District, U.S. Army Corps of Engineers.

HydroQual. 2002. A Water Quality Model for Jamaica Bay: Calibration of the Jamaica Bay Eutrophication Model (JEM). Final Draft. Prepared for the City of New York Department of Environmental Protection. Under subcontract to O'Brien and Gere Engineers, Inc.

Will, R. 2006. Personal Communication. U.S. Army Corps of Engineers, New York District.

# APPENDIX A

# VERTICAL PROFILE FIGURES

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— Model Output

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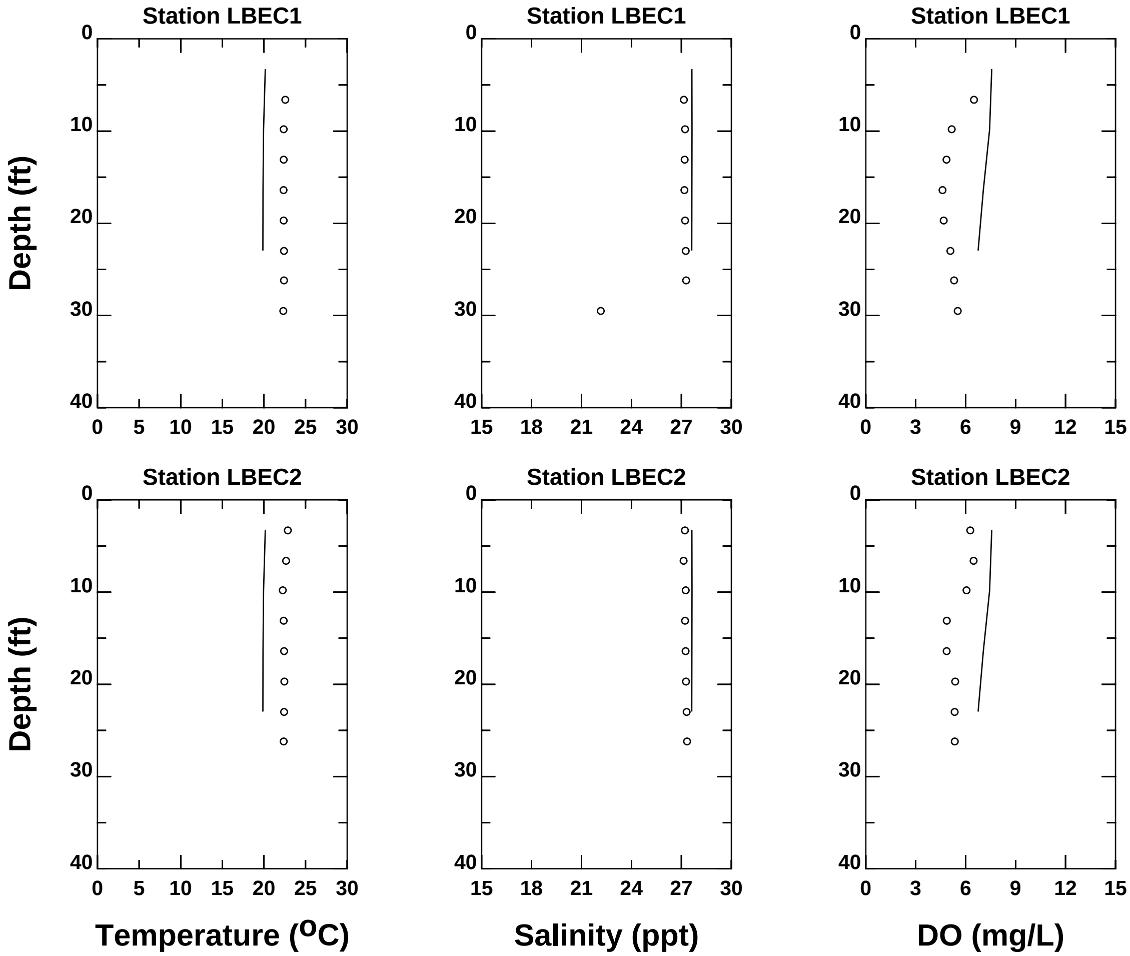


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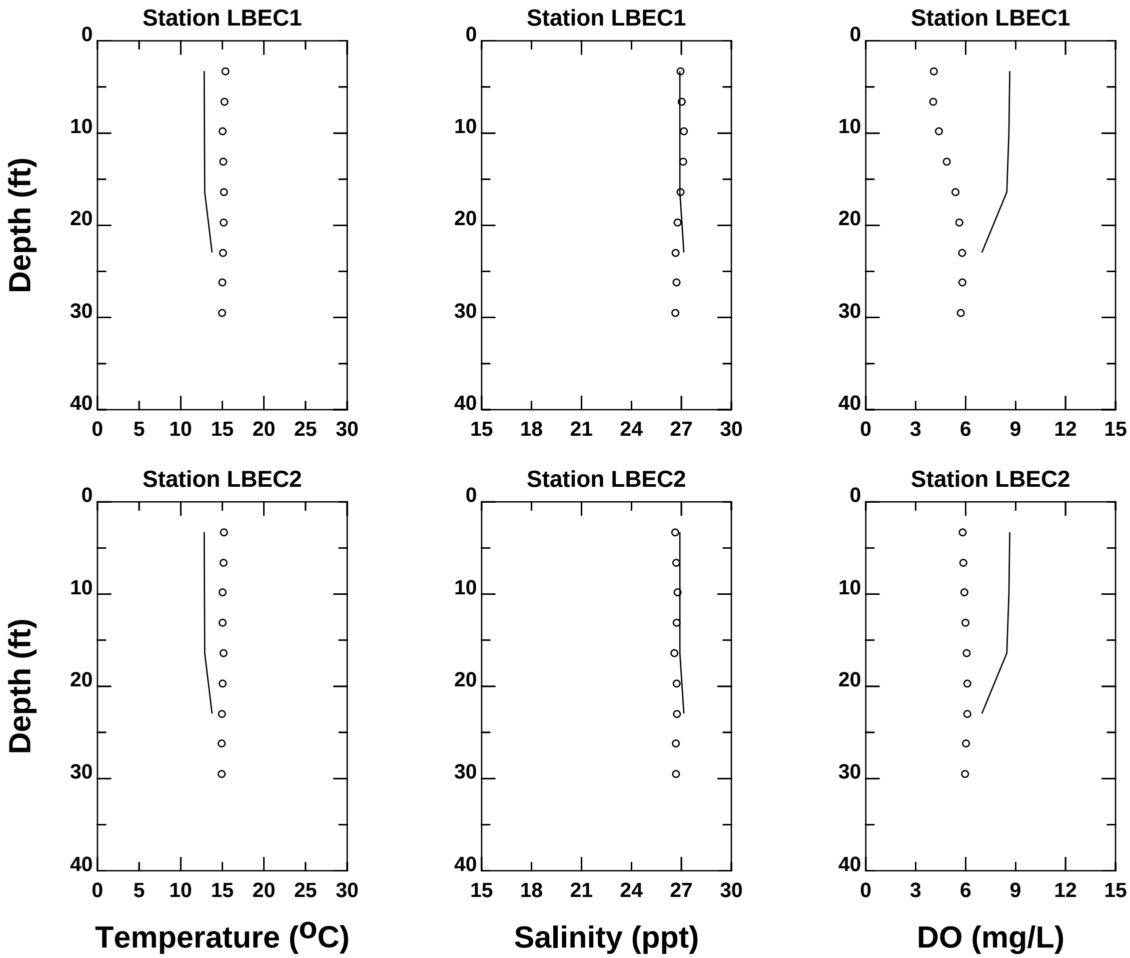


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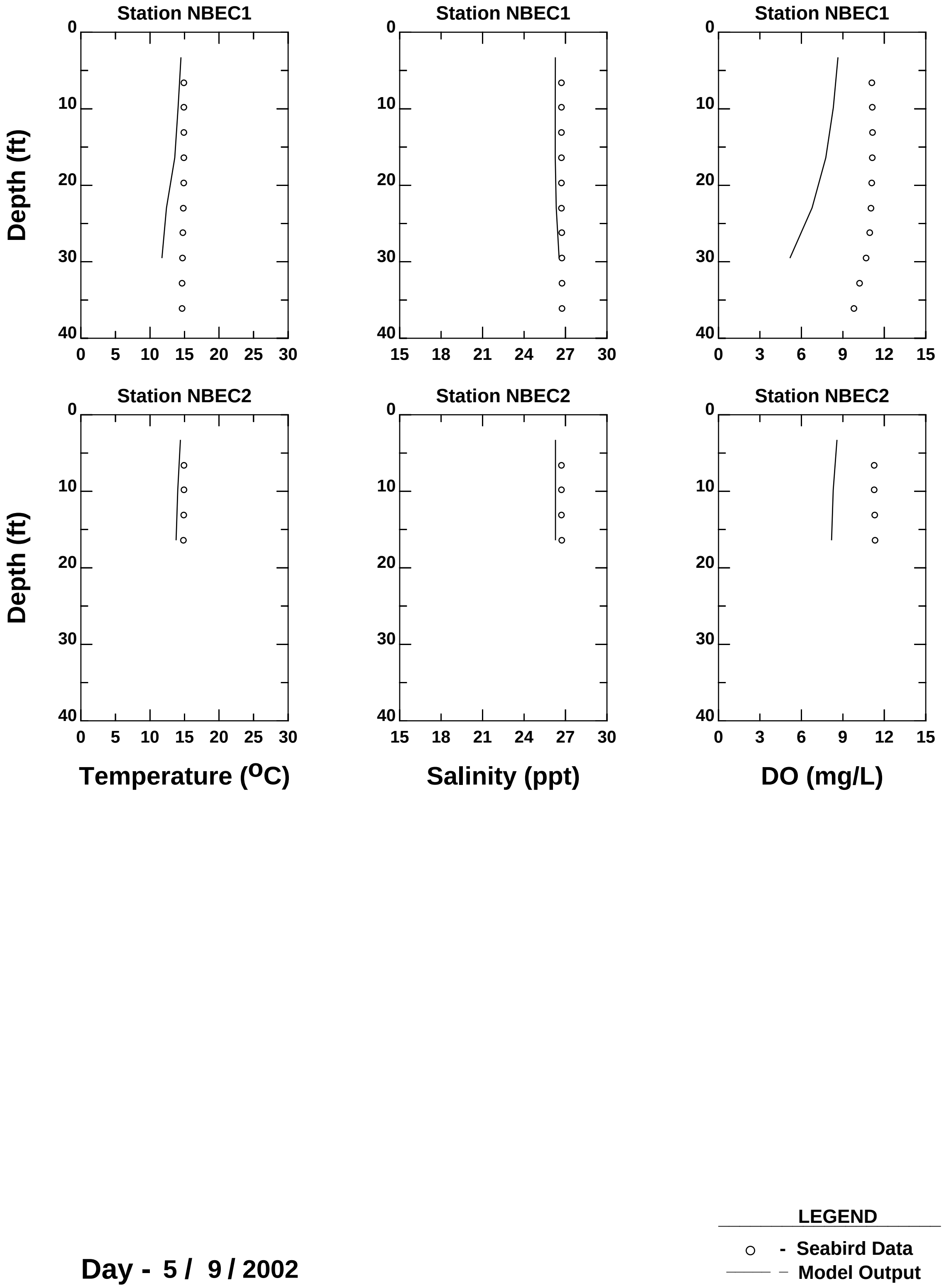


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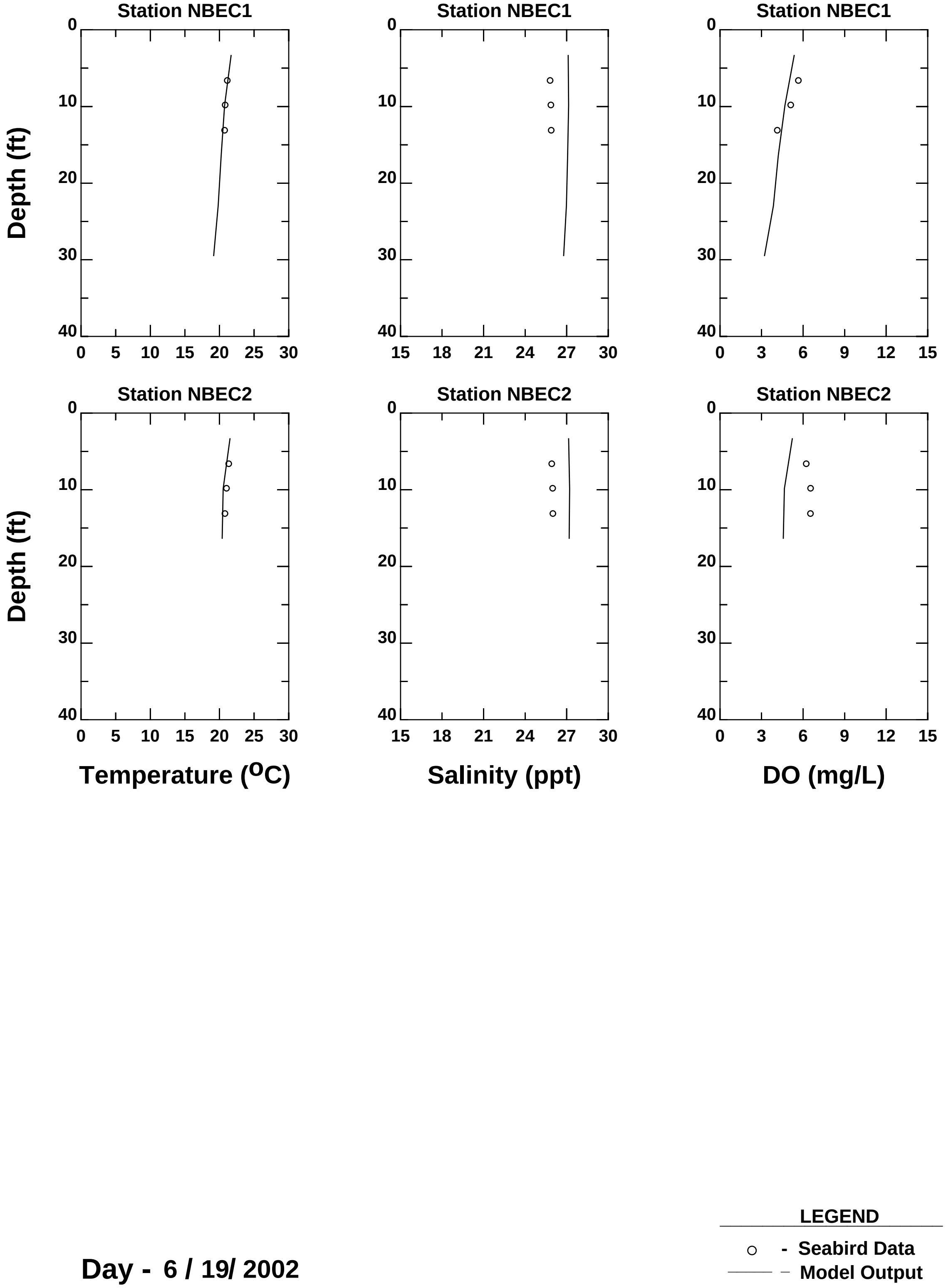


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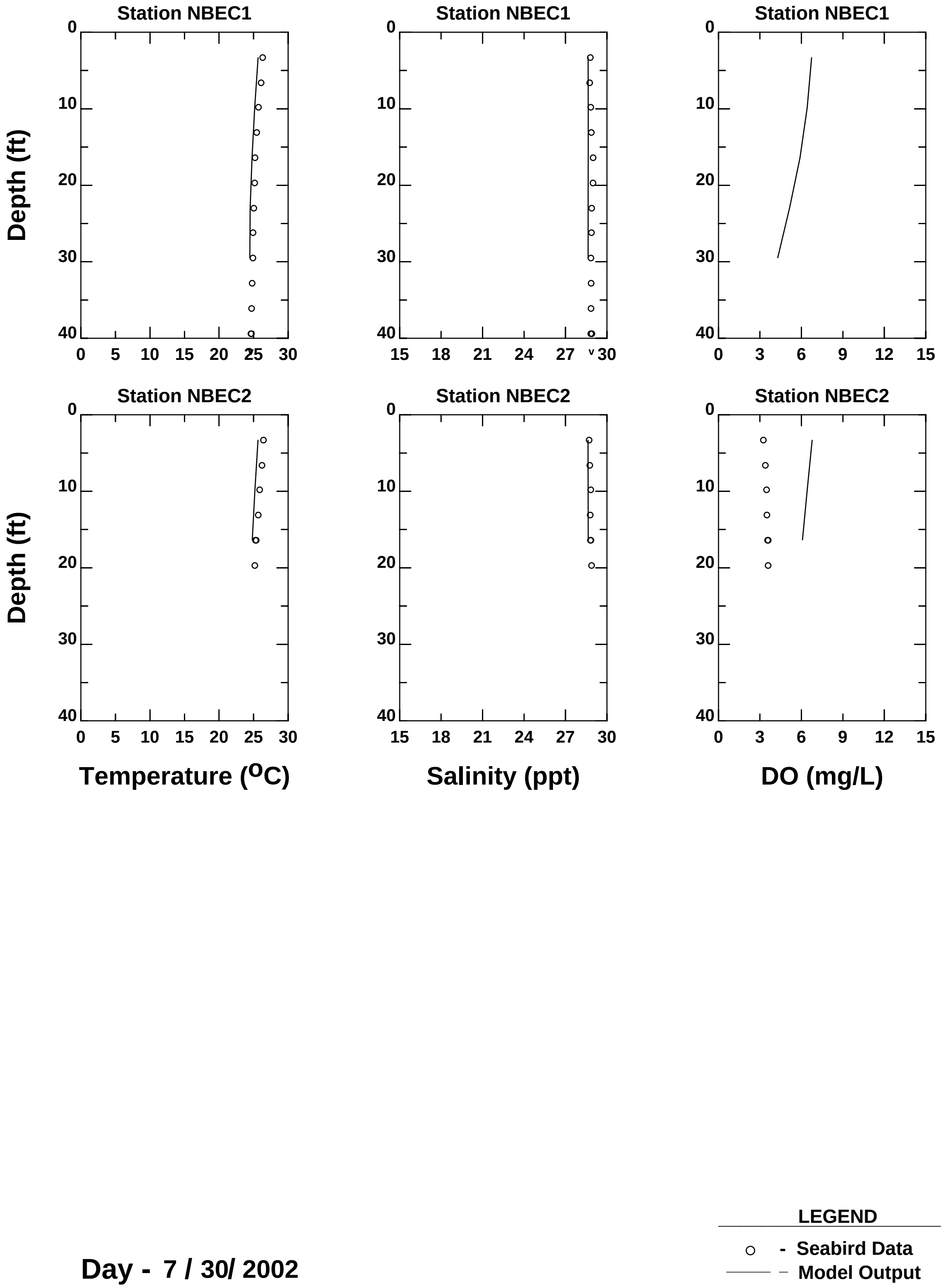


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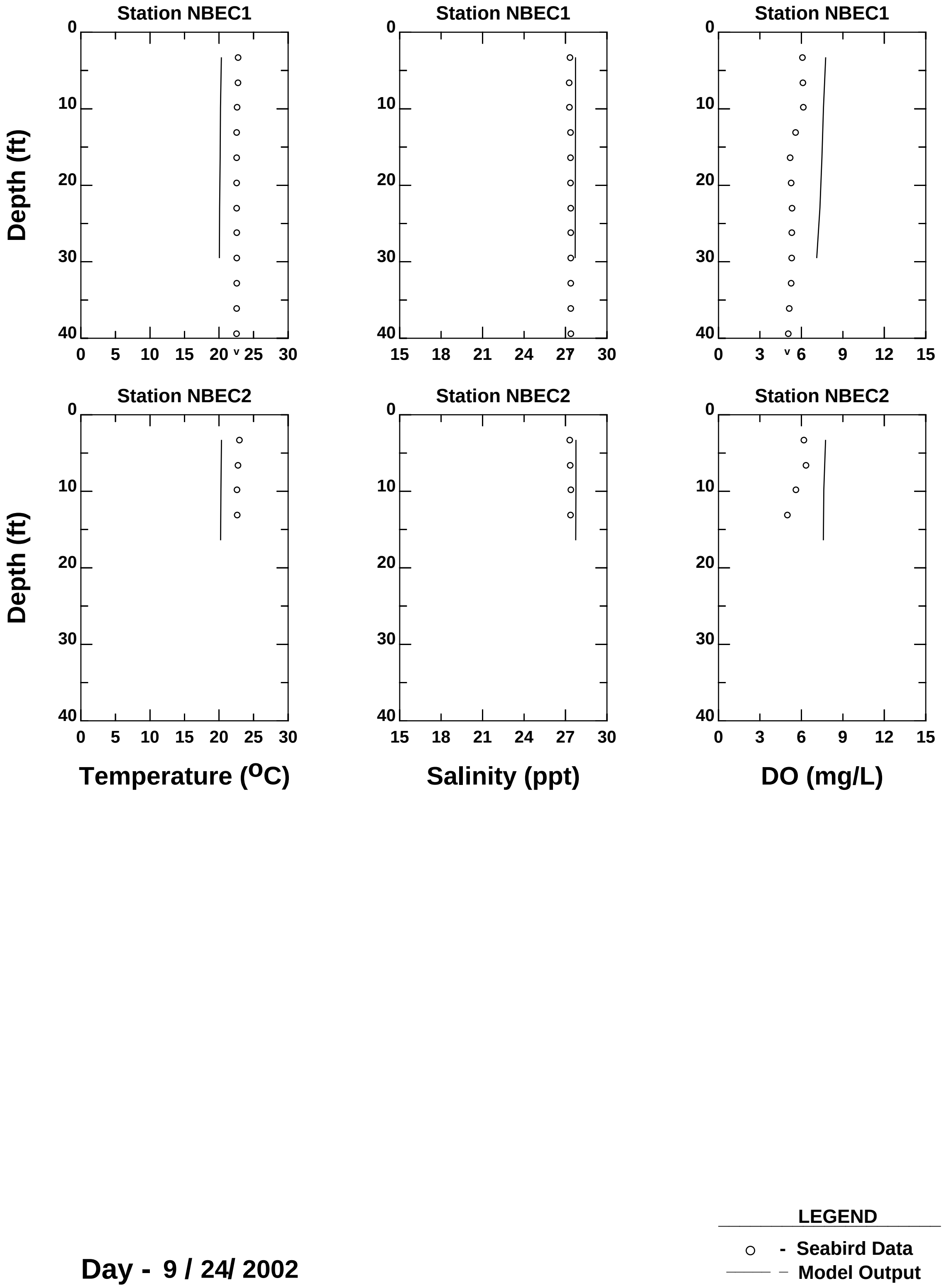


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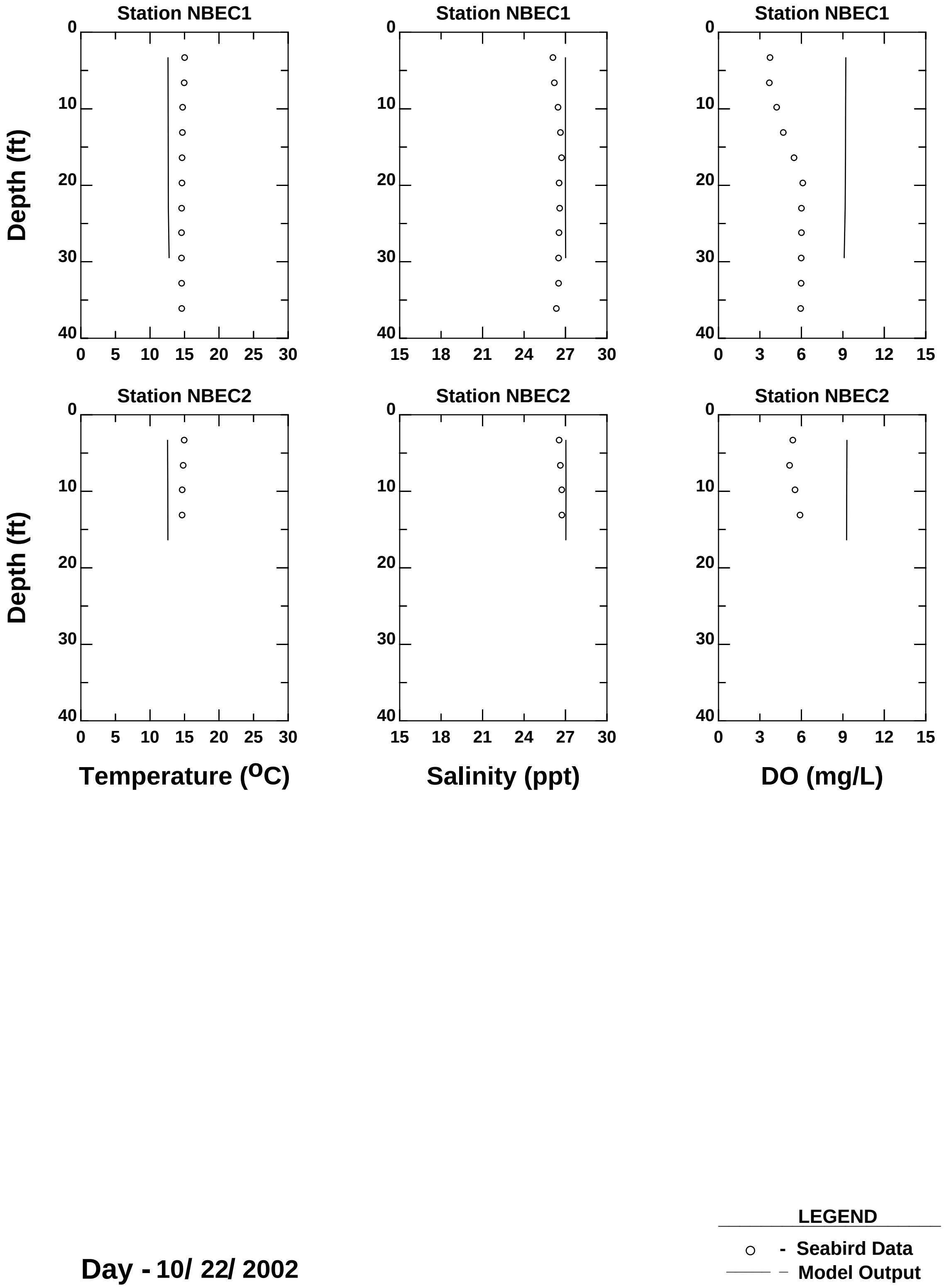


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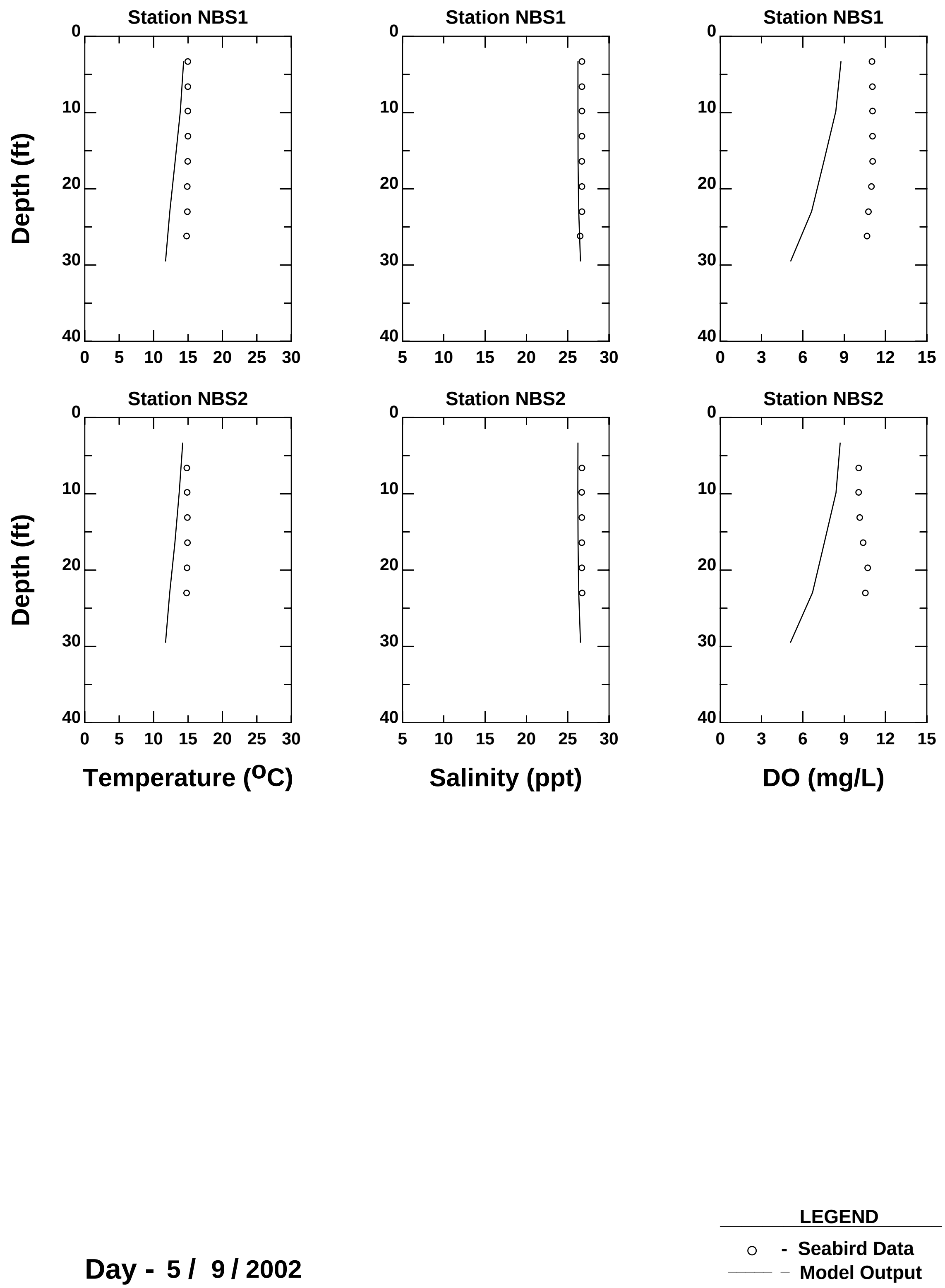


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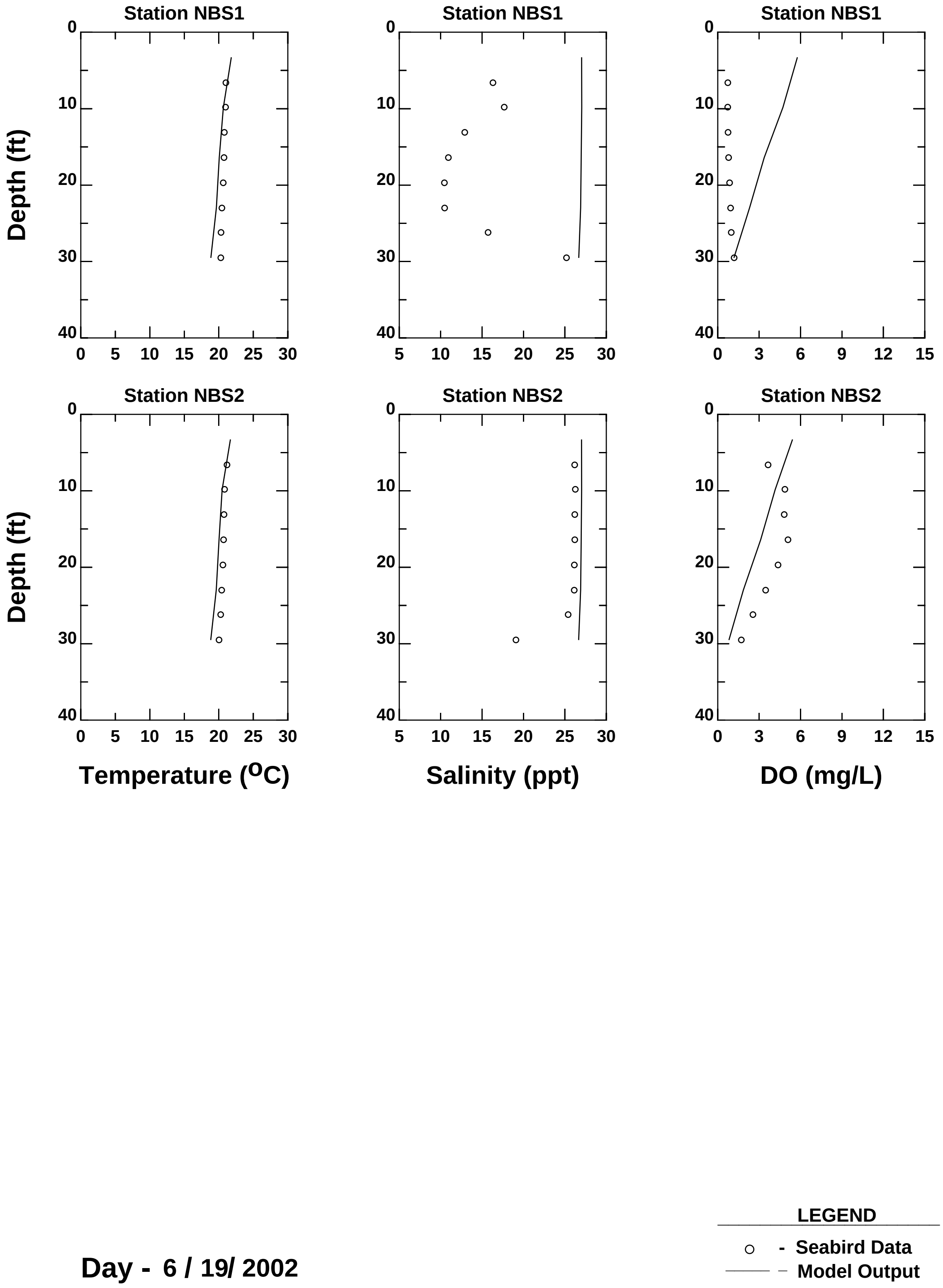
Norton Basin Model, Vertical Profile in Norton Basin Shallows

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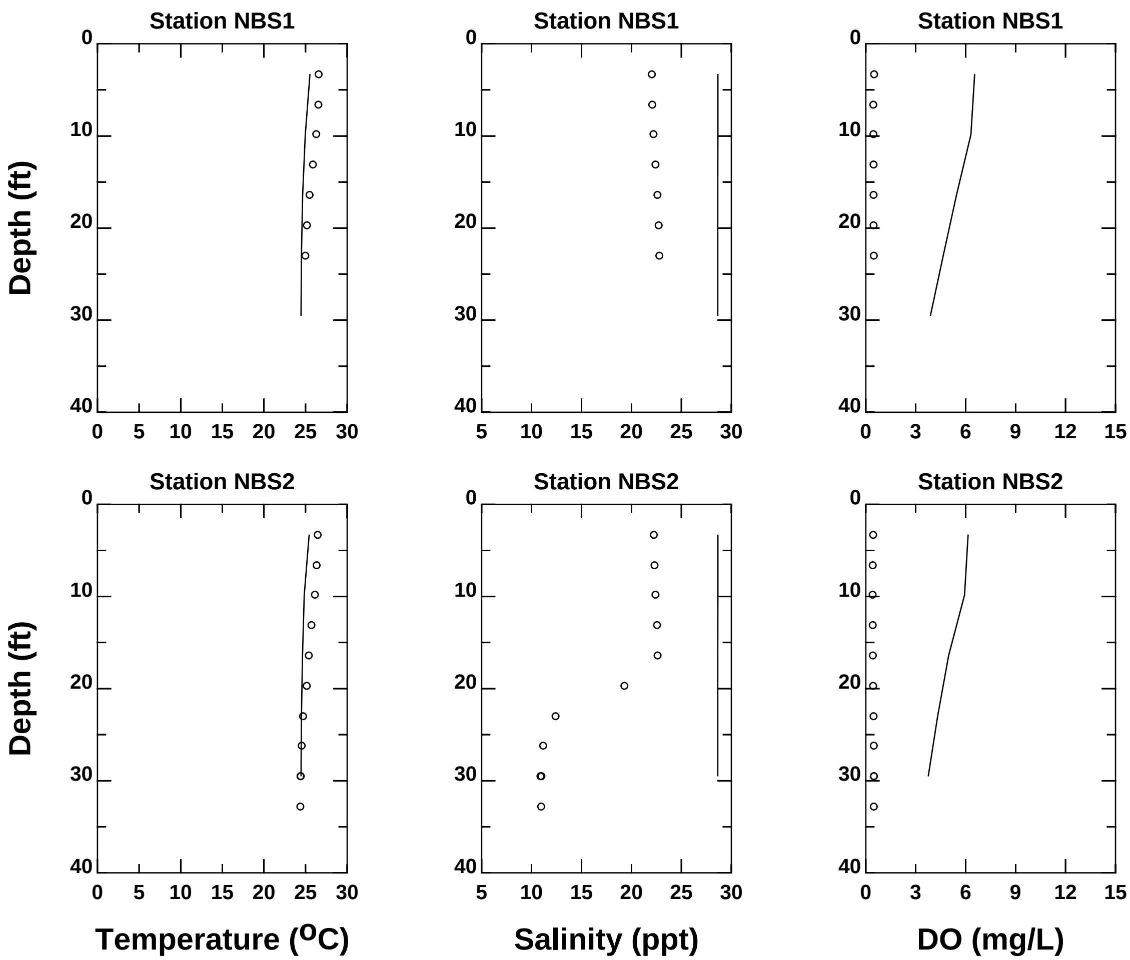


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— Model Output

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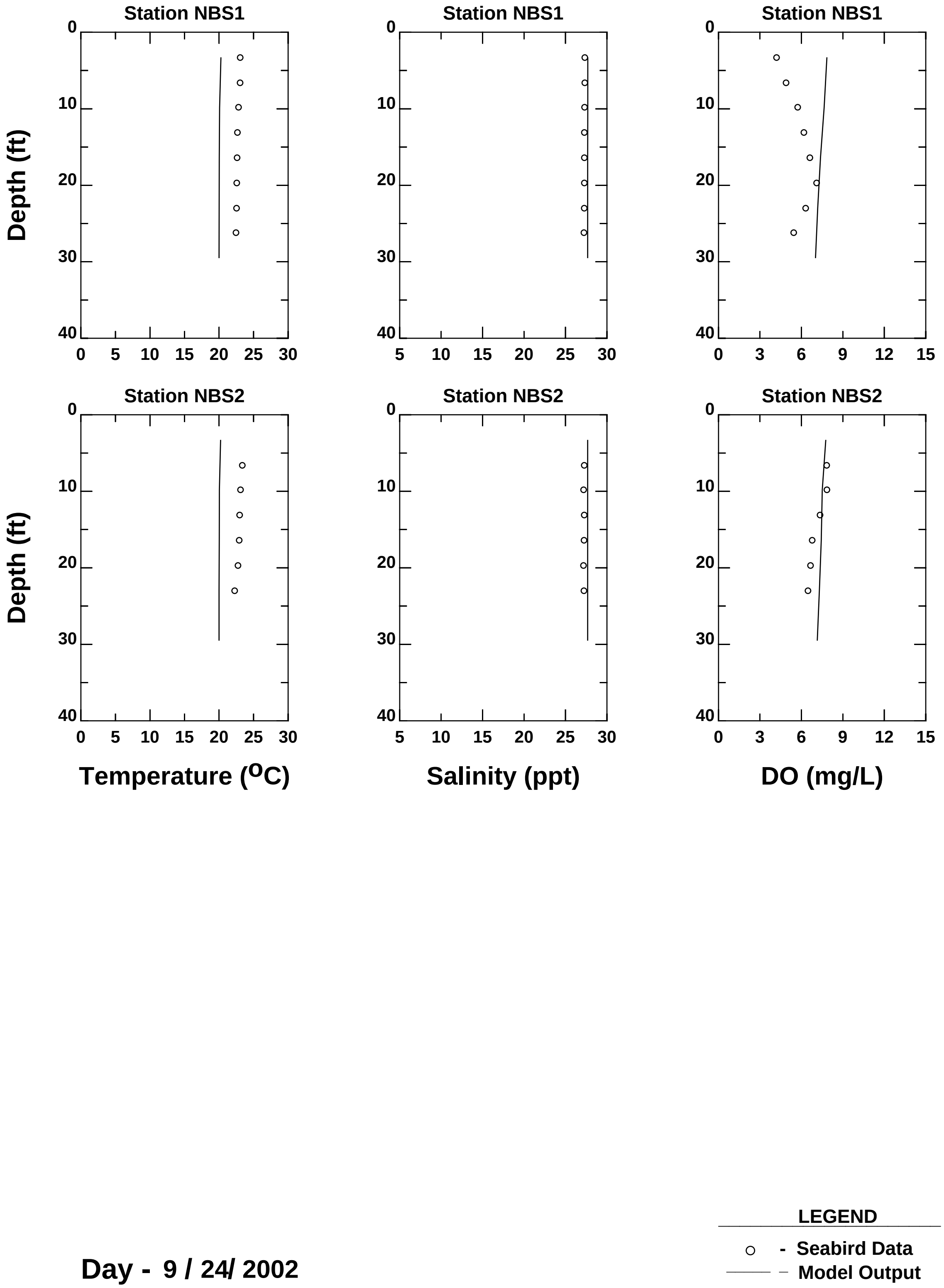


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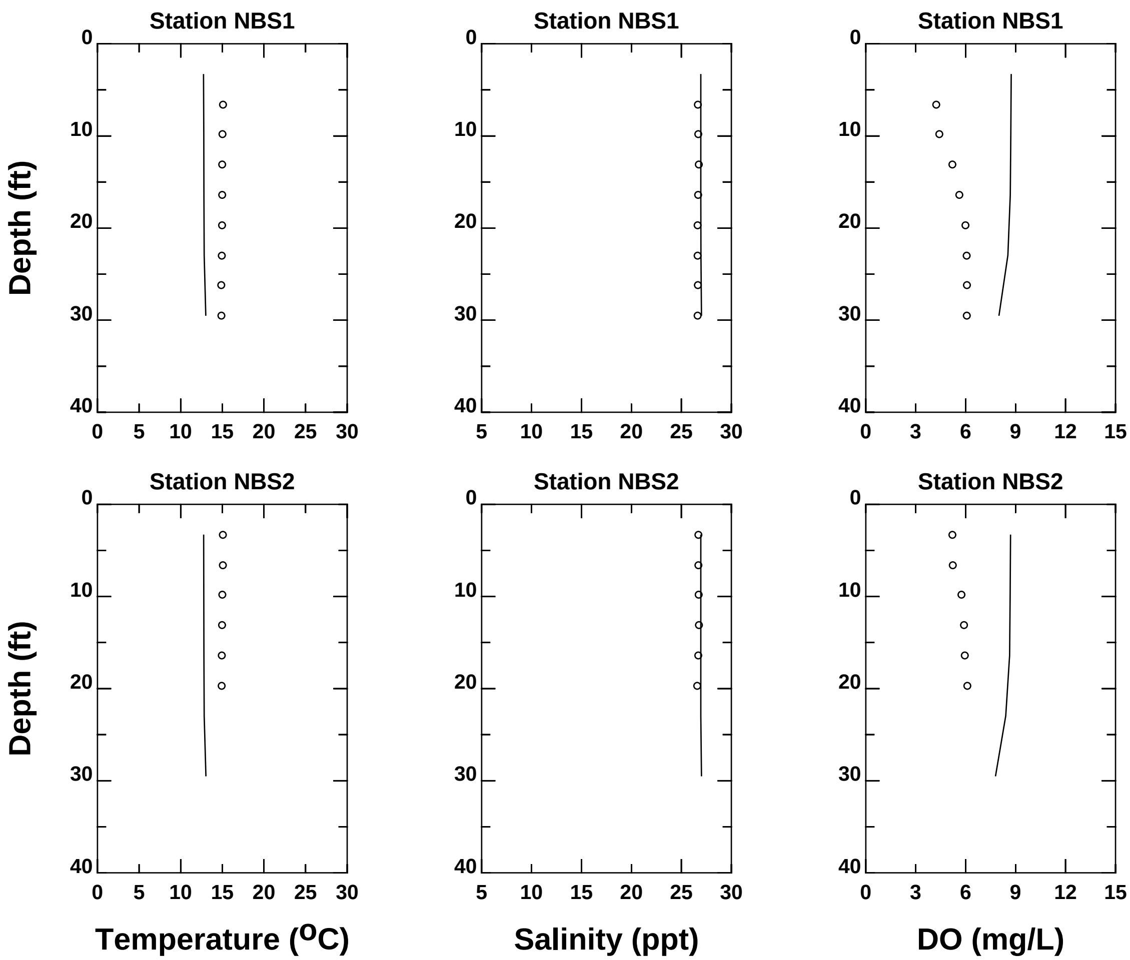


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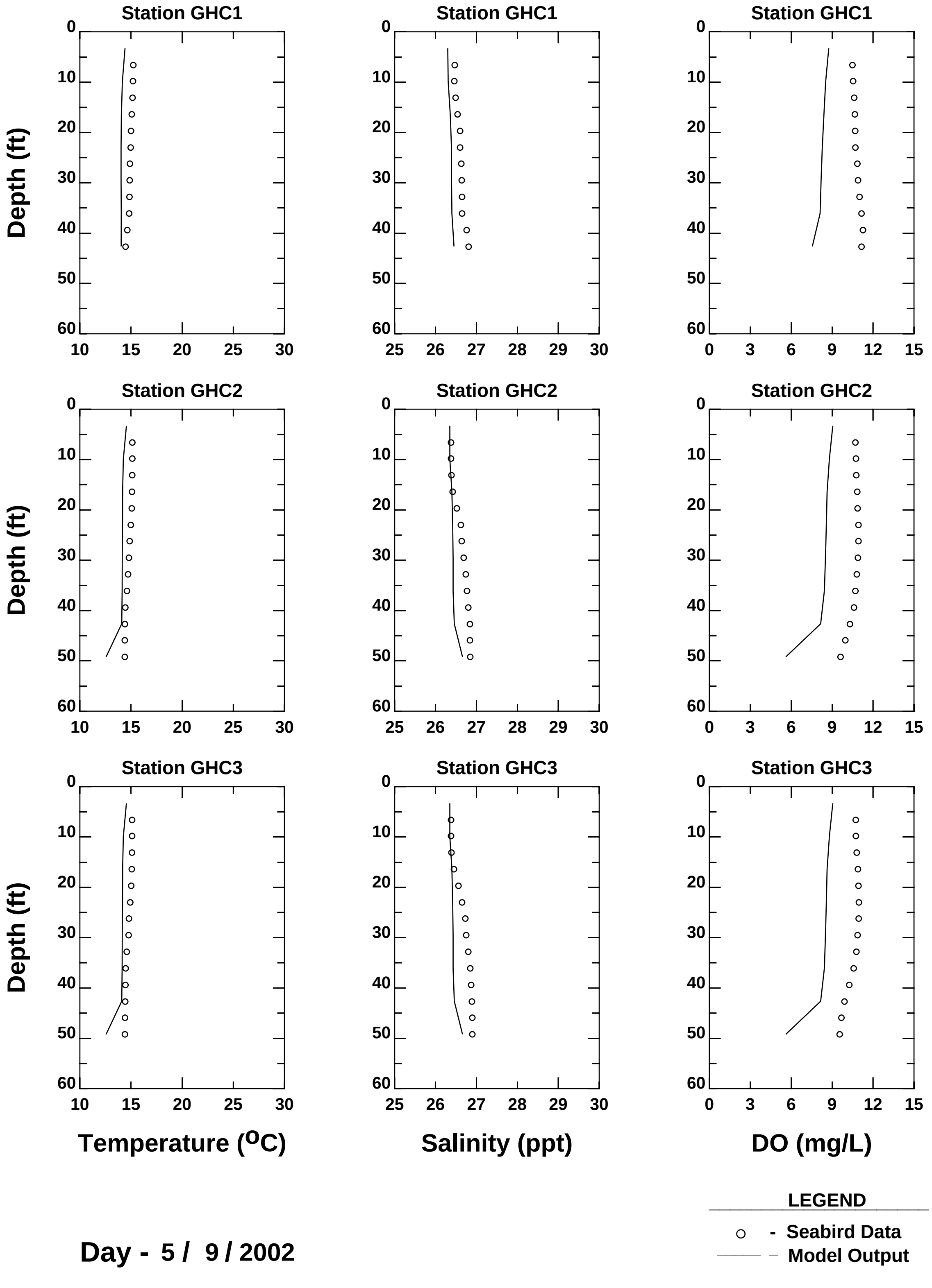


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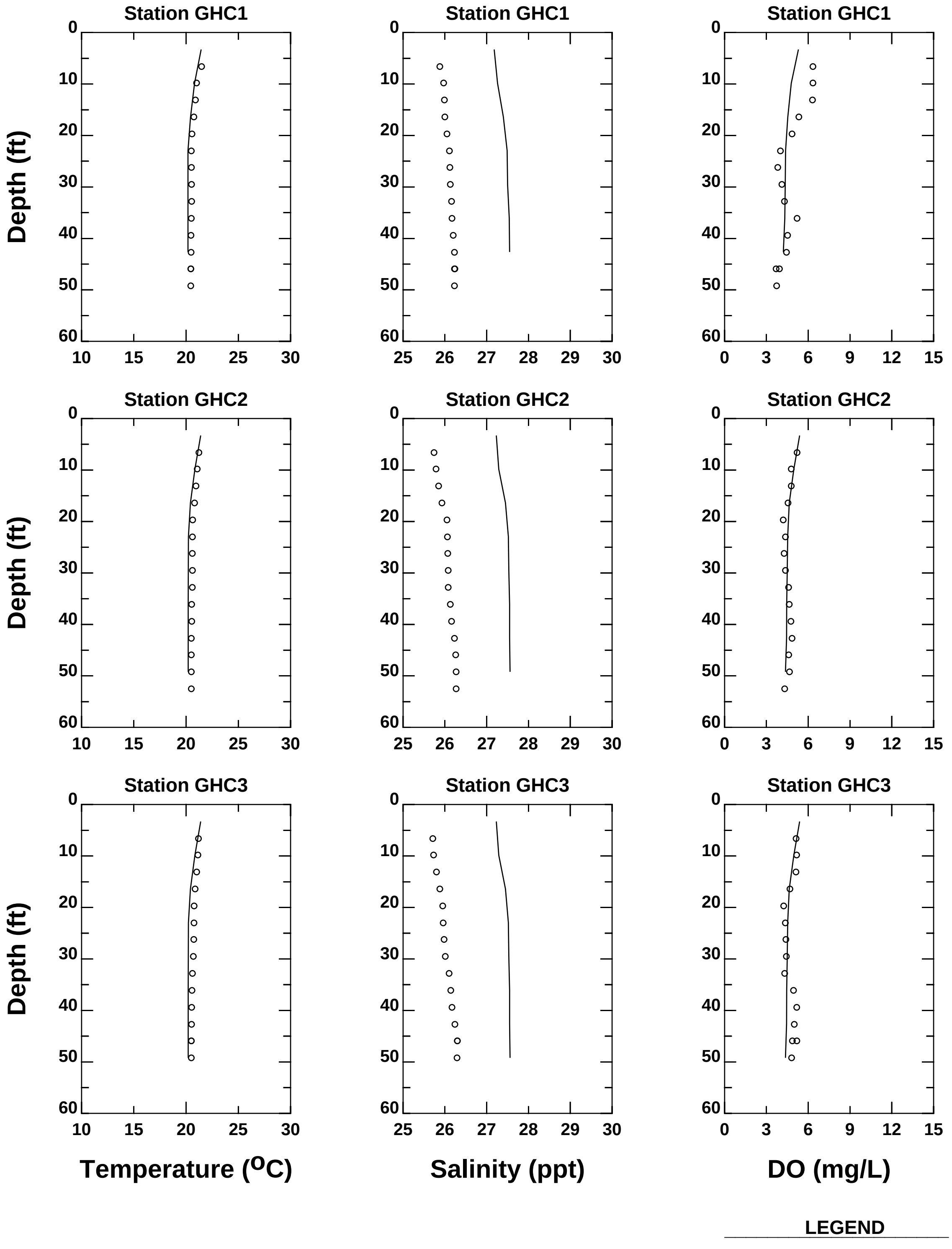
Norton Basin Model, Vertical Profile in Grass Hassock Channel

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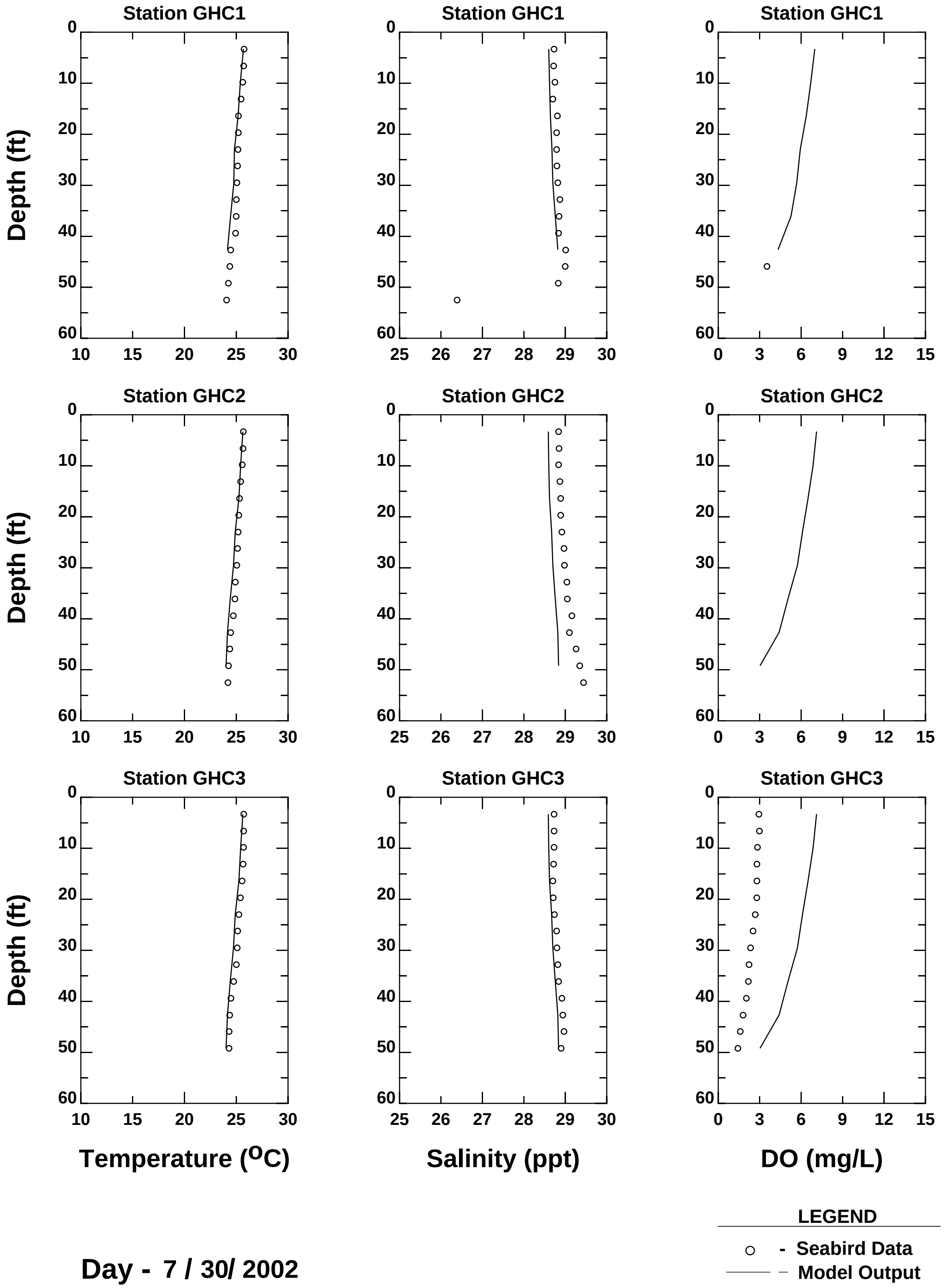


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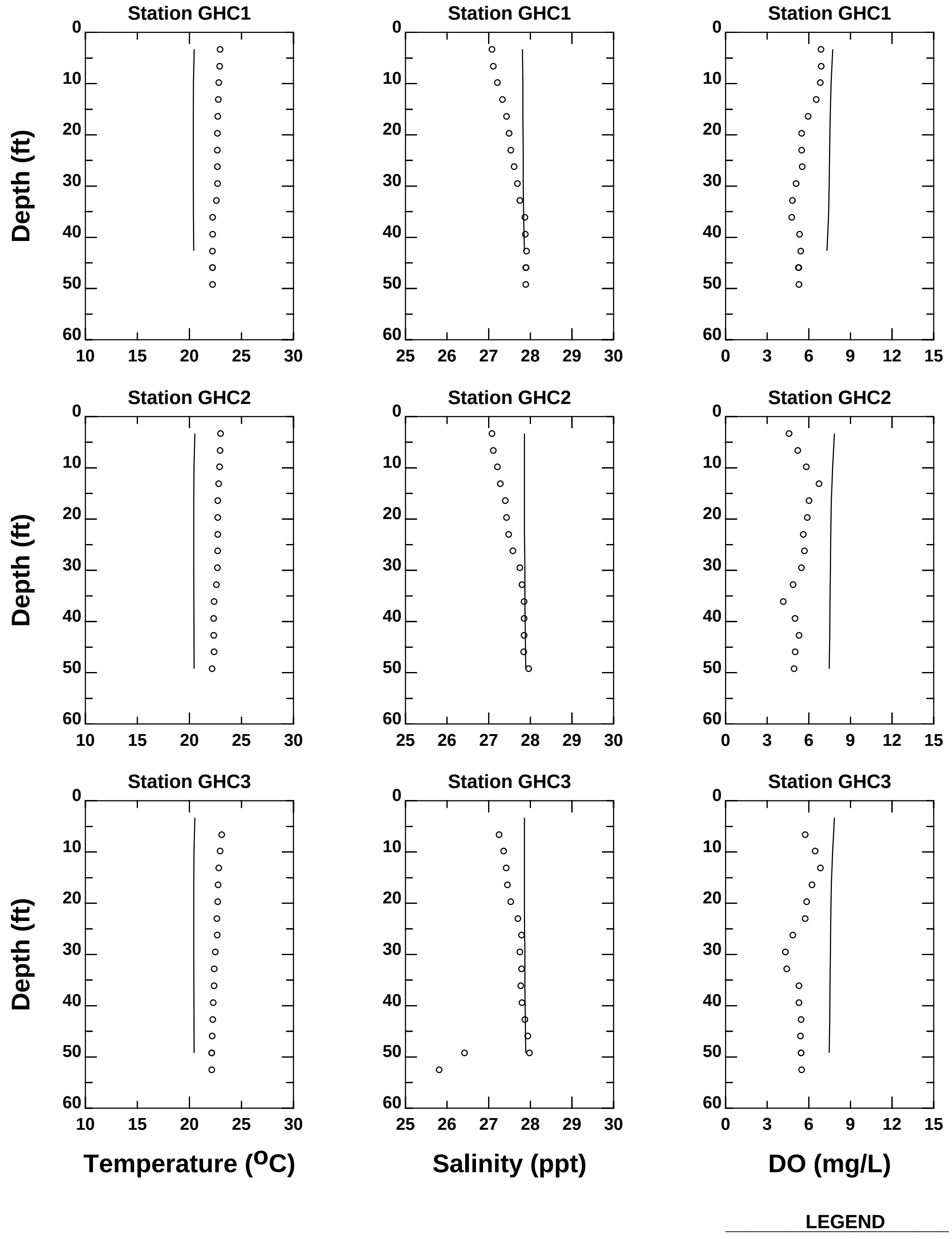


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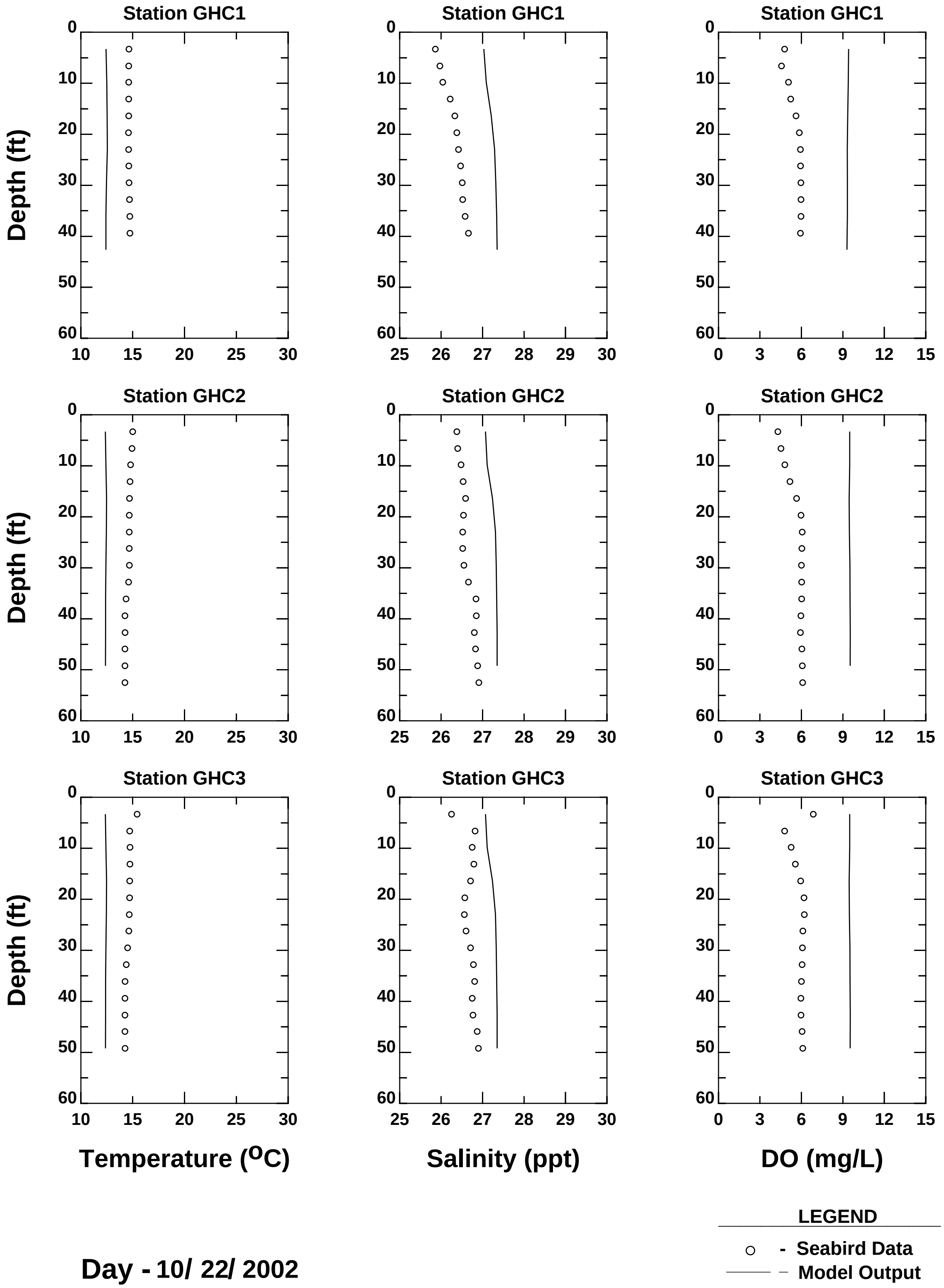


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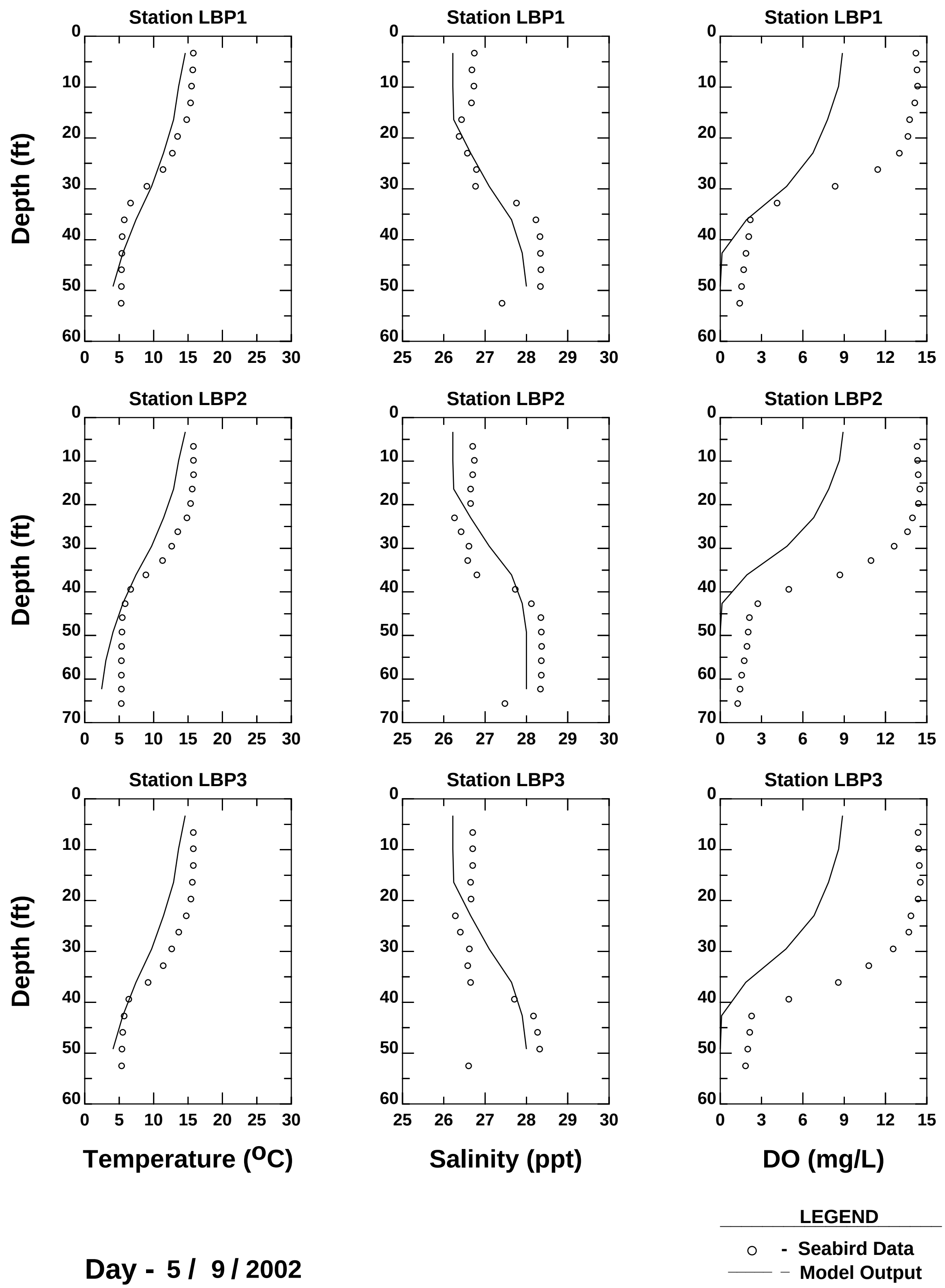


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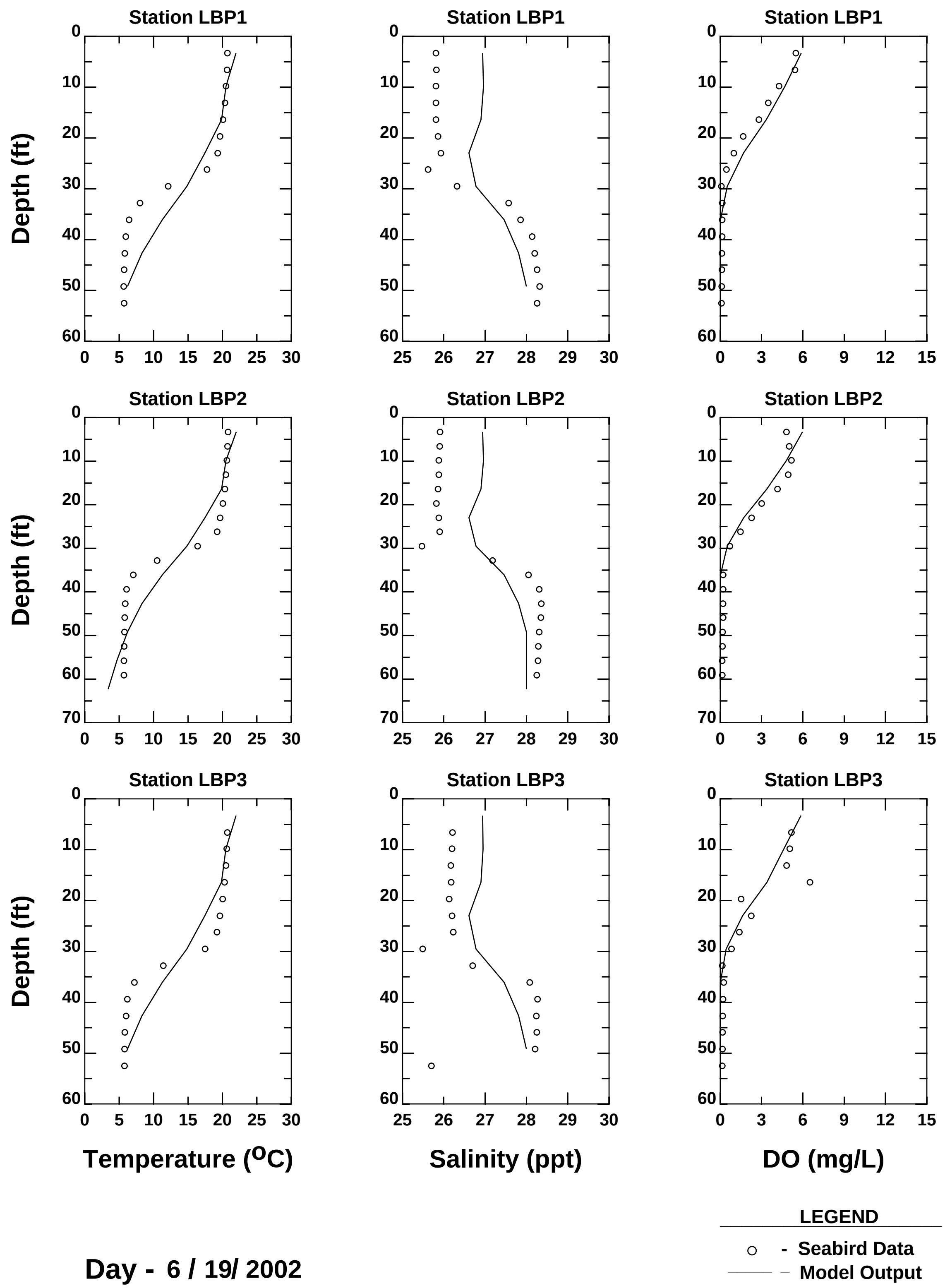


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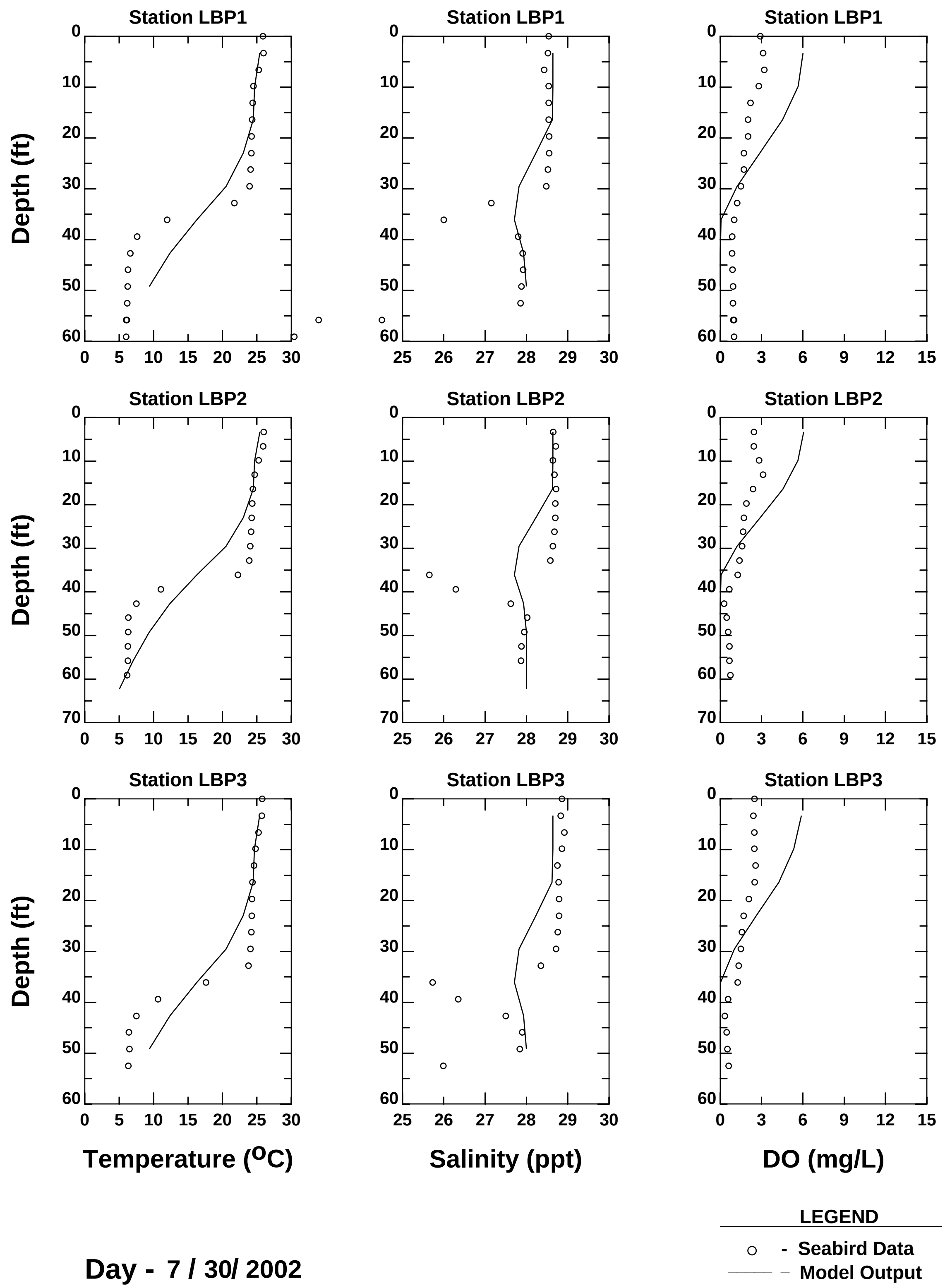


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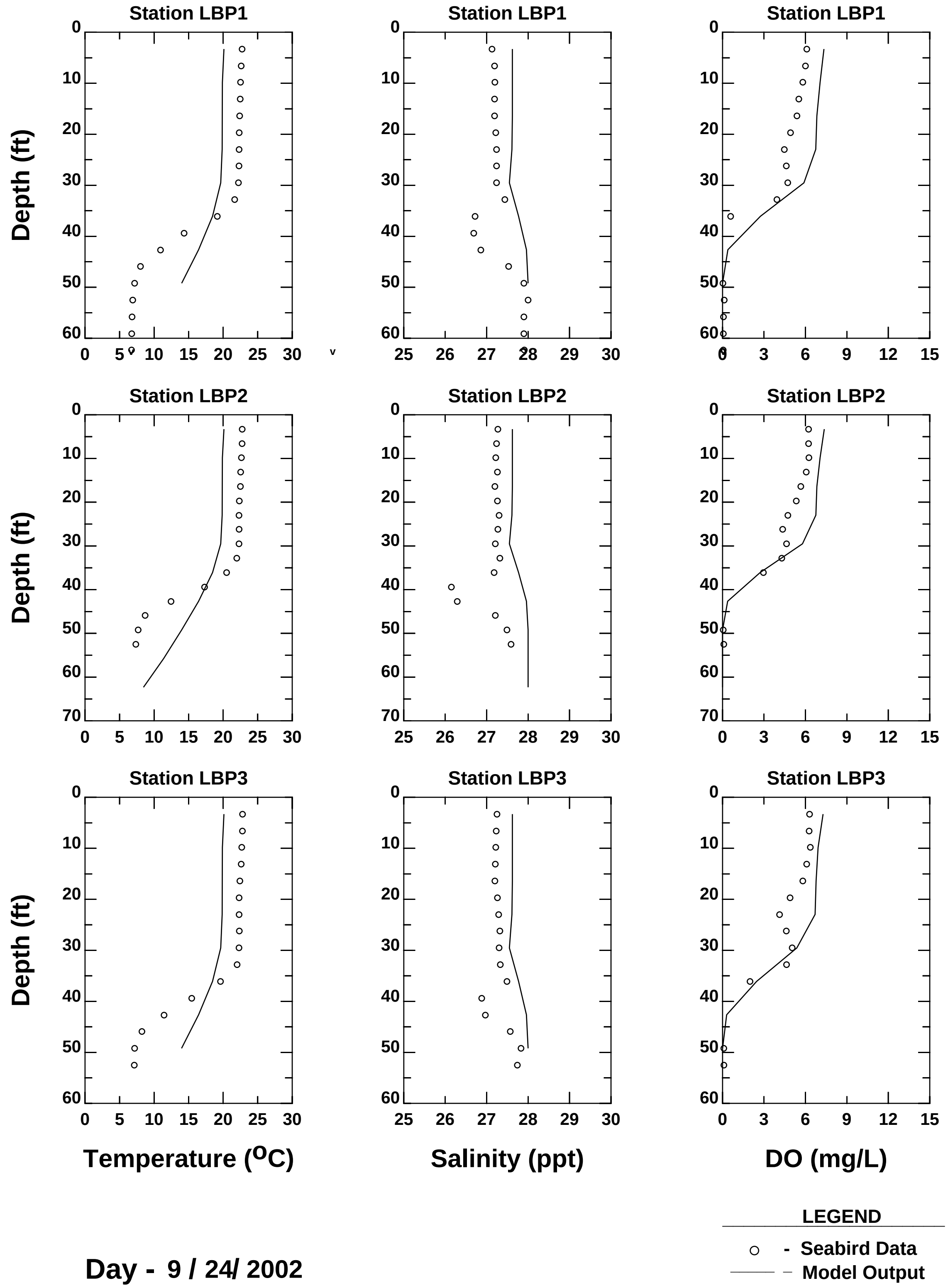


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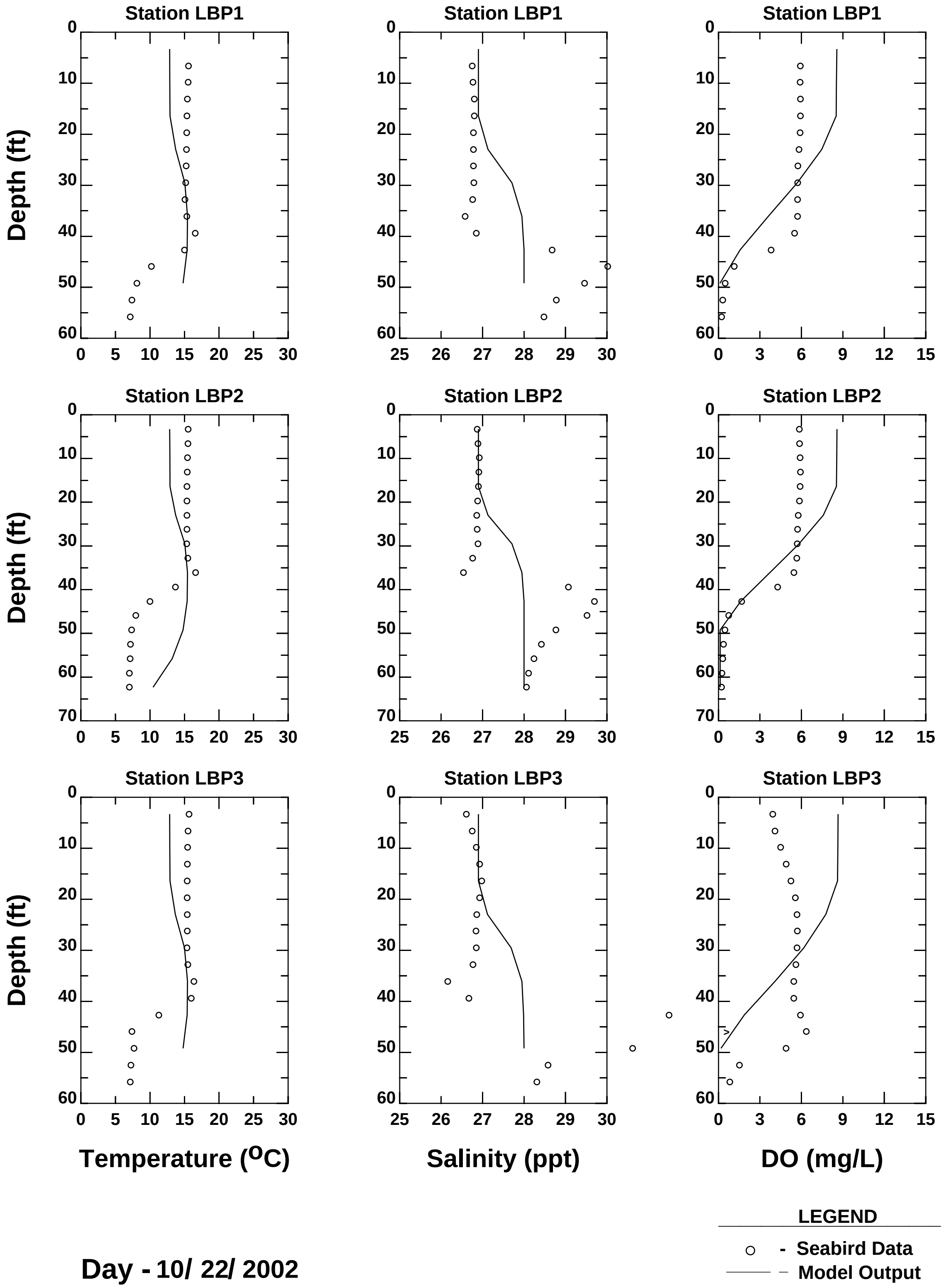


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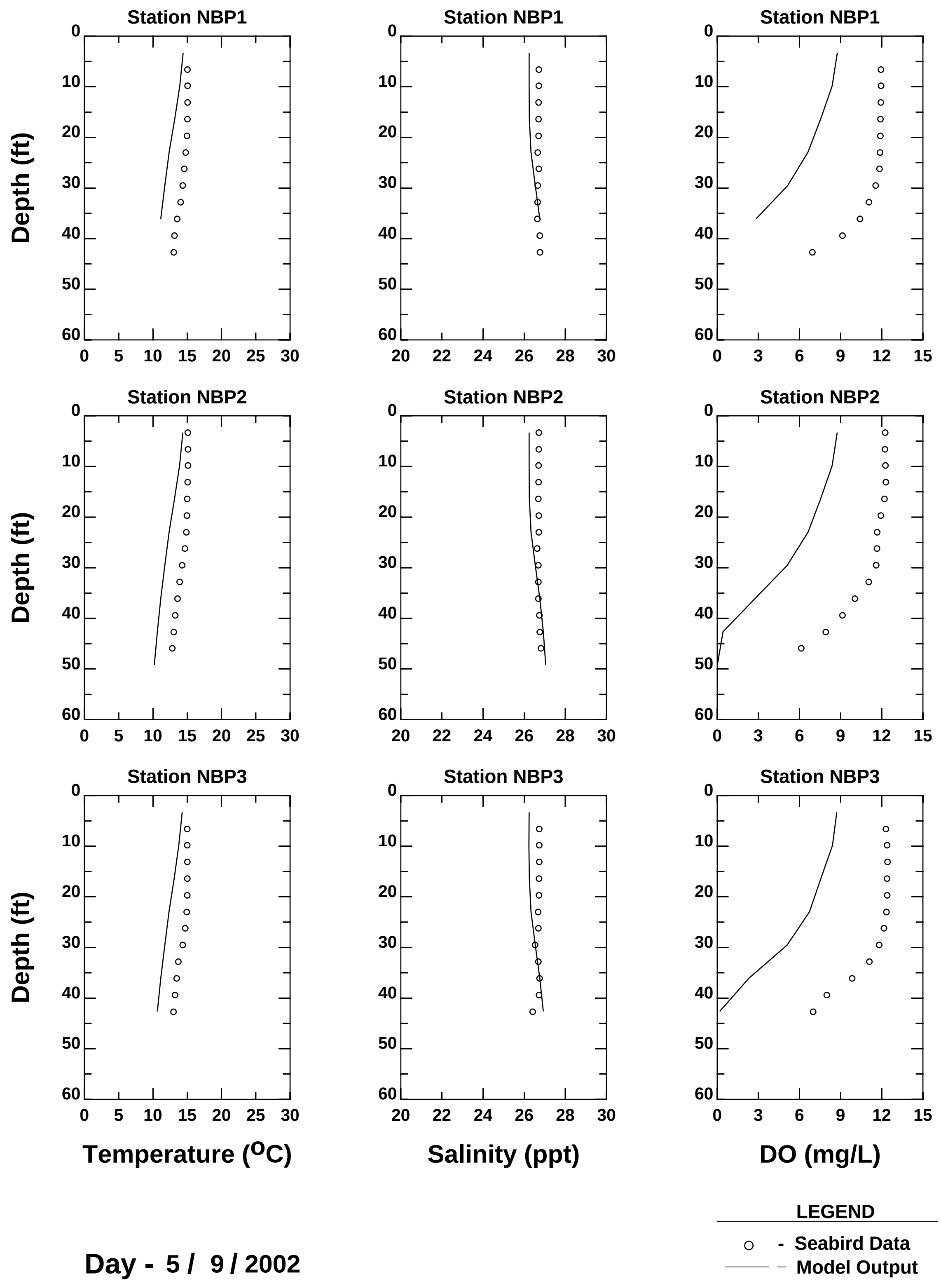


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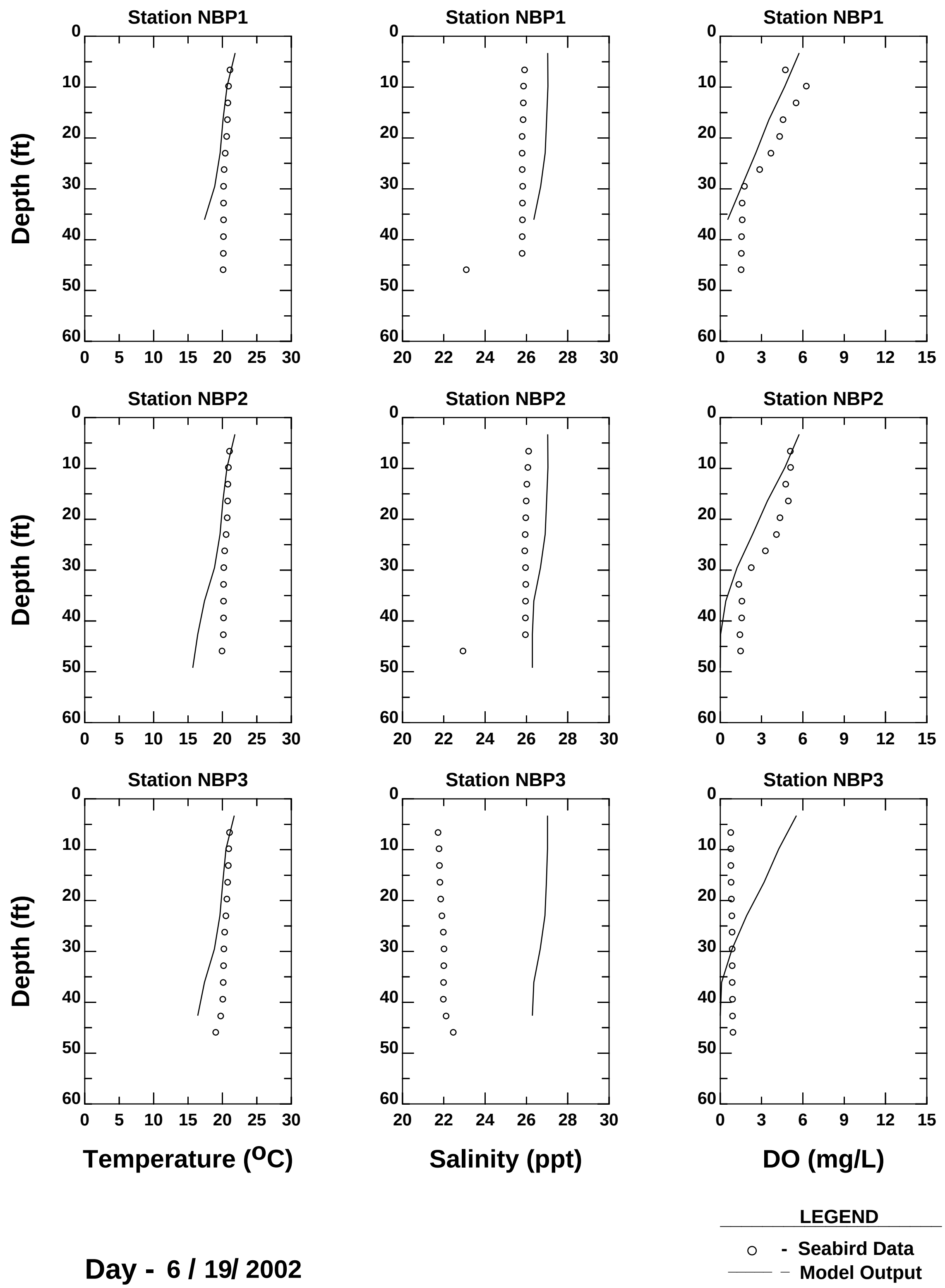


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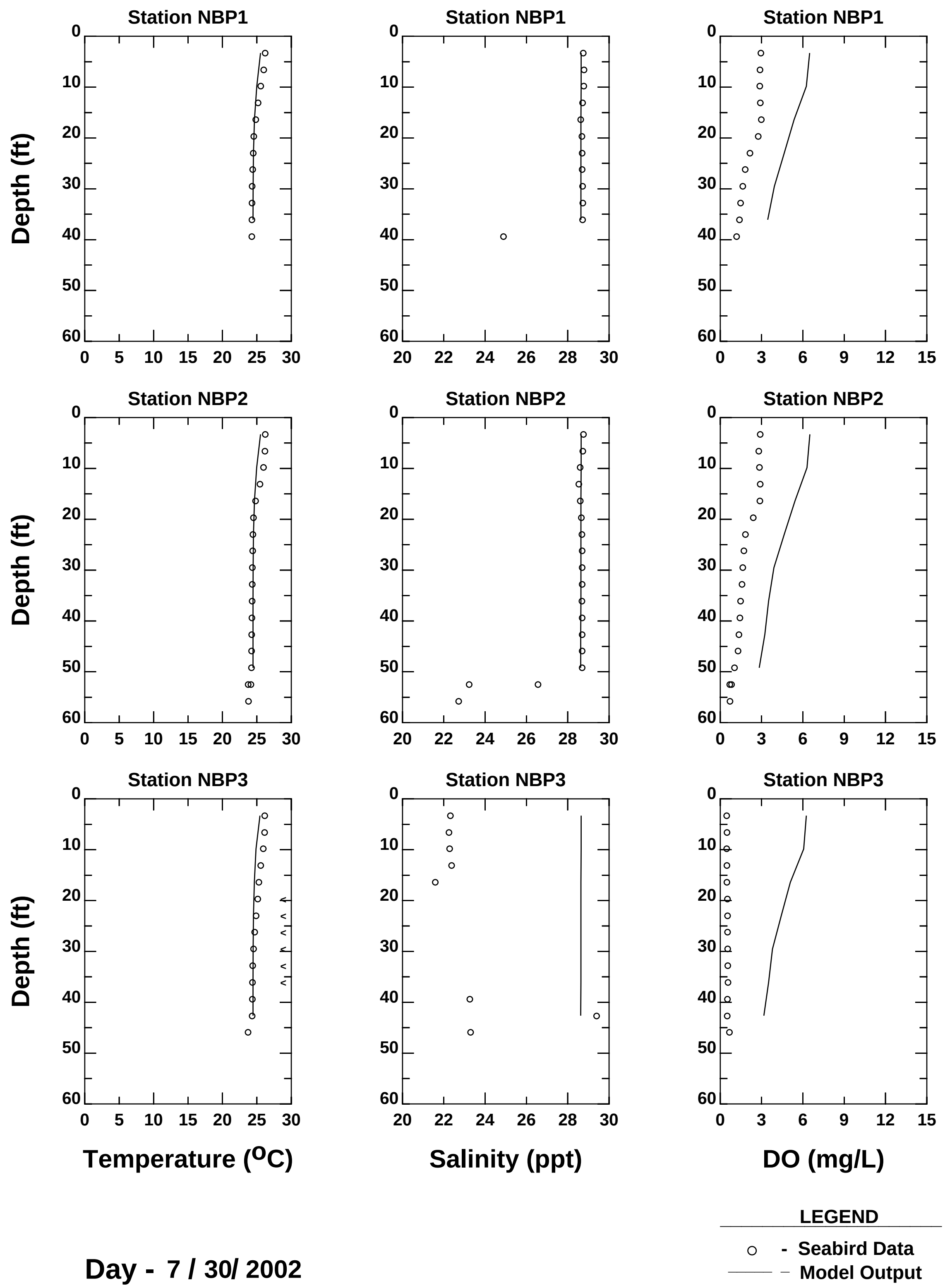


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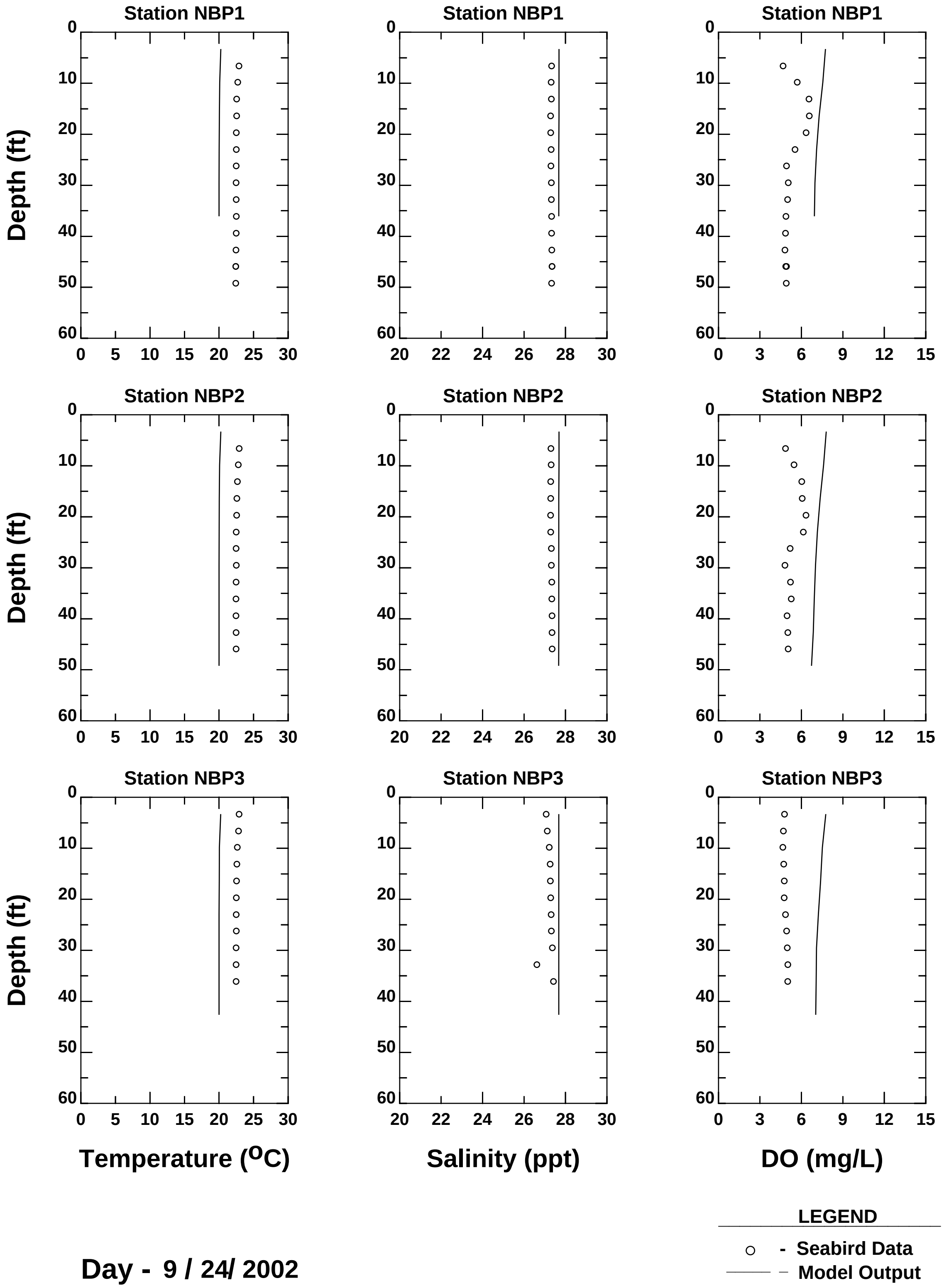


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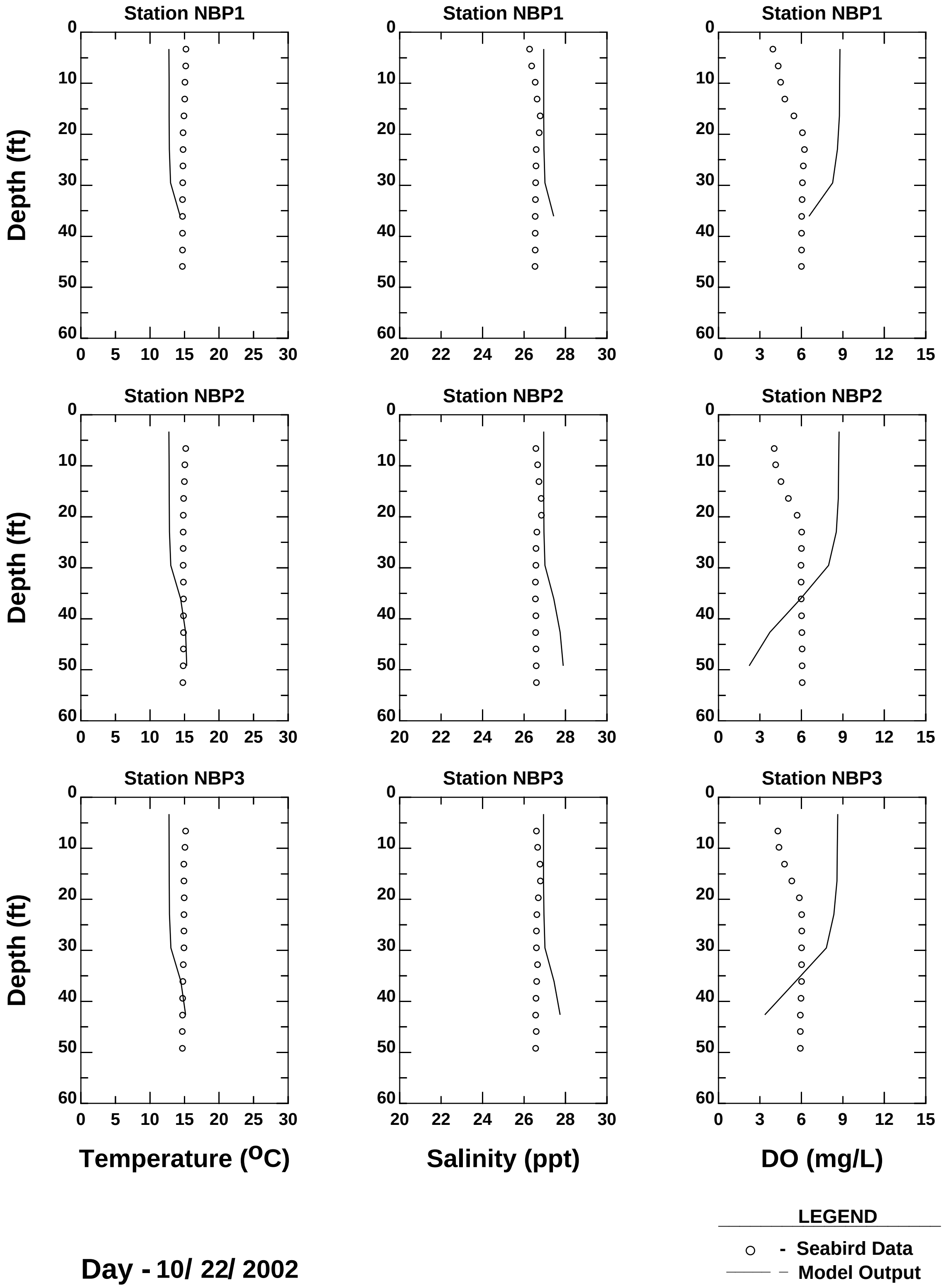


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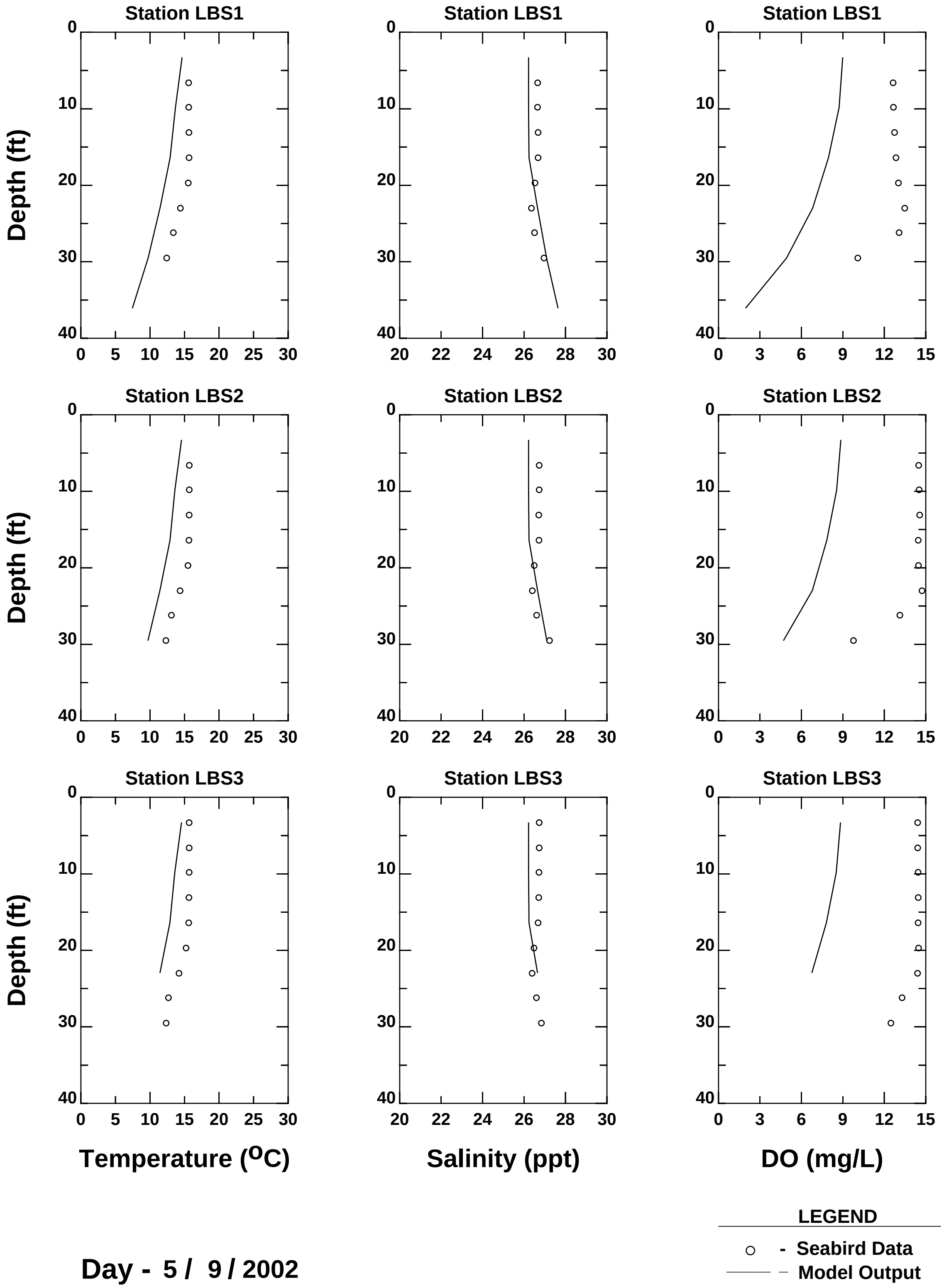


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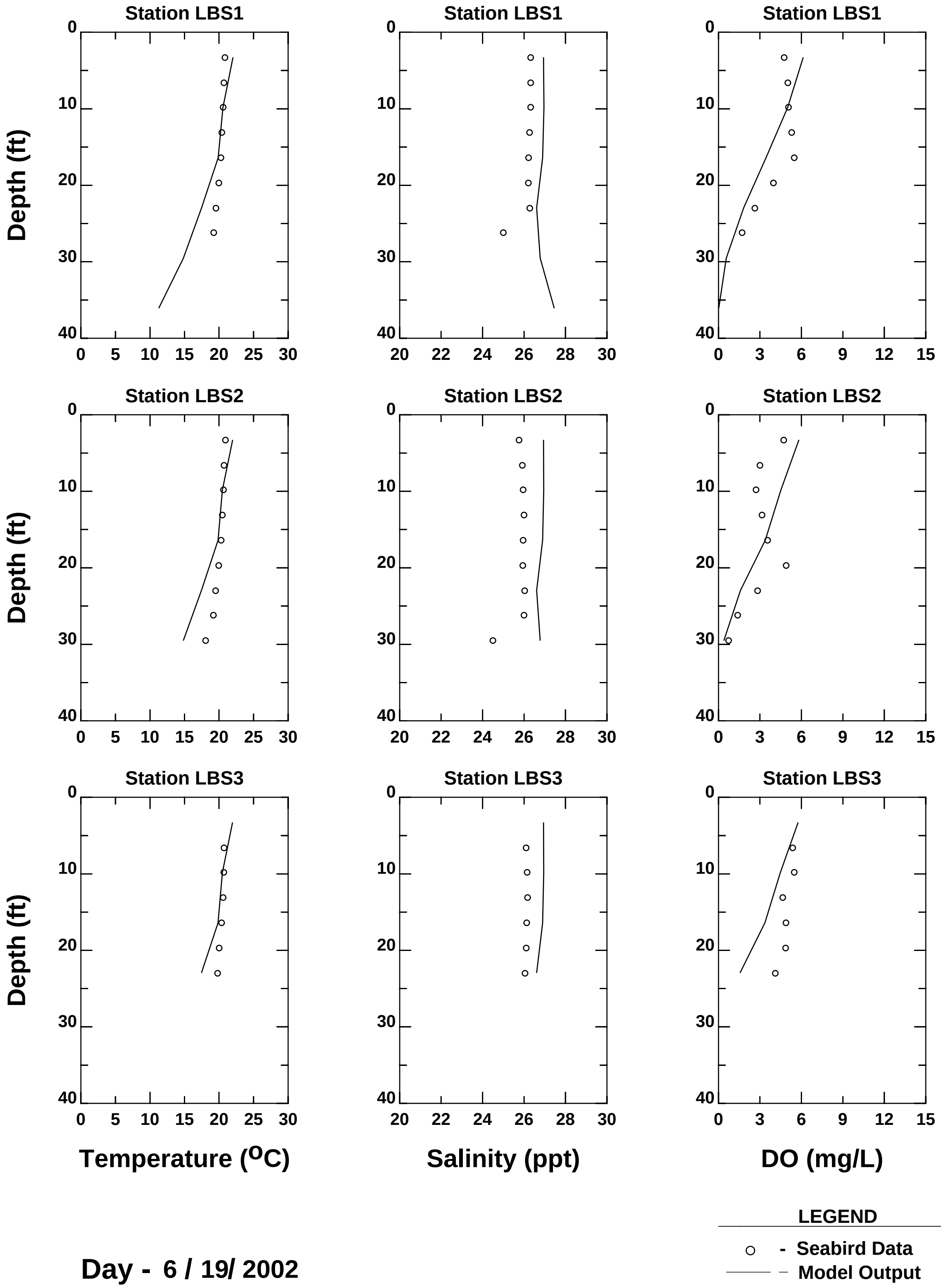
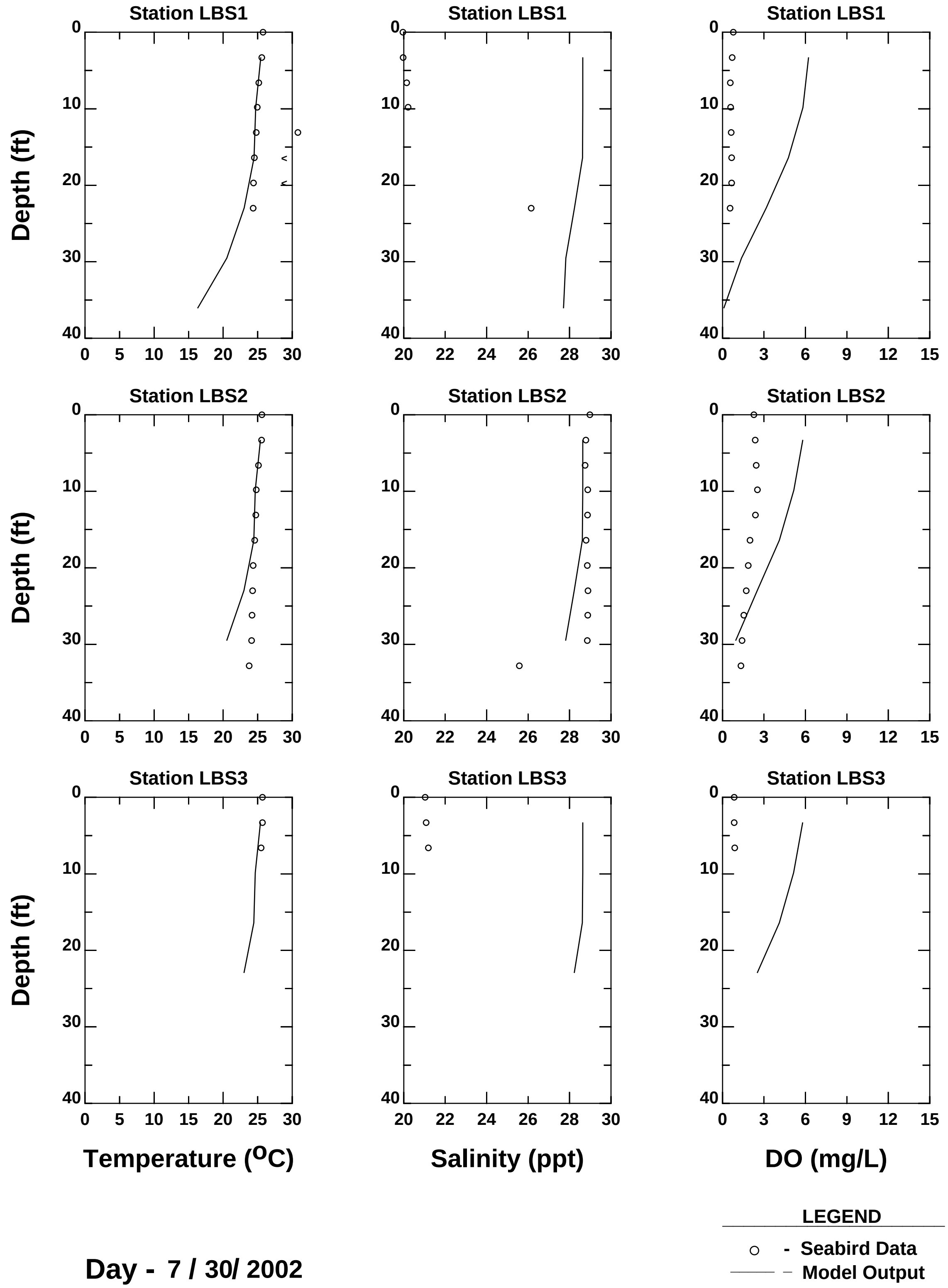


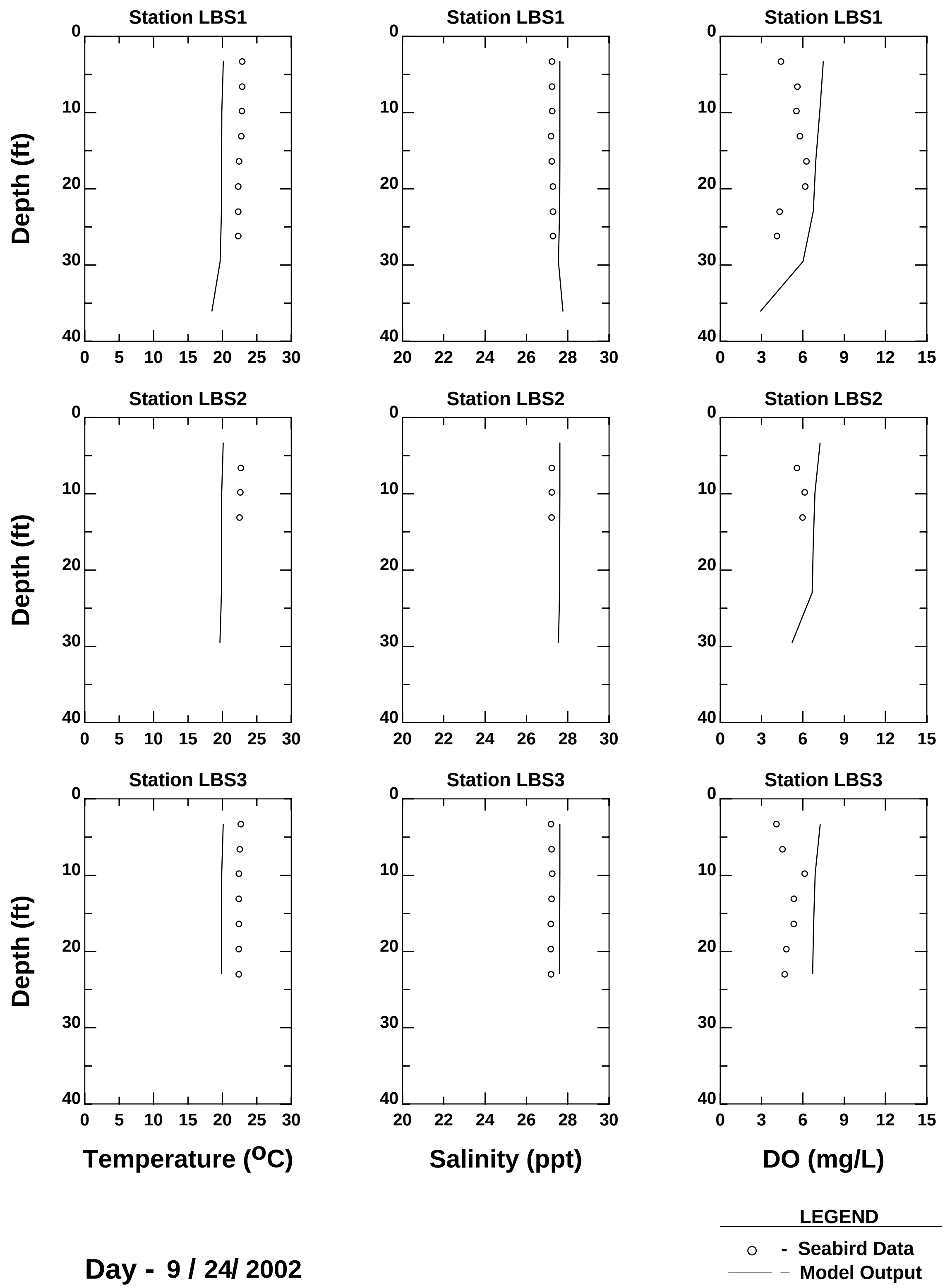

Day - 6 / 19/ 2002

Norton Basin Model, Vertical Profile in Little Bay Shallows



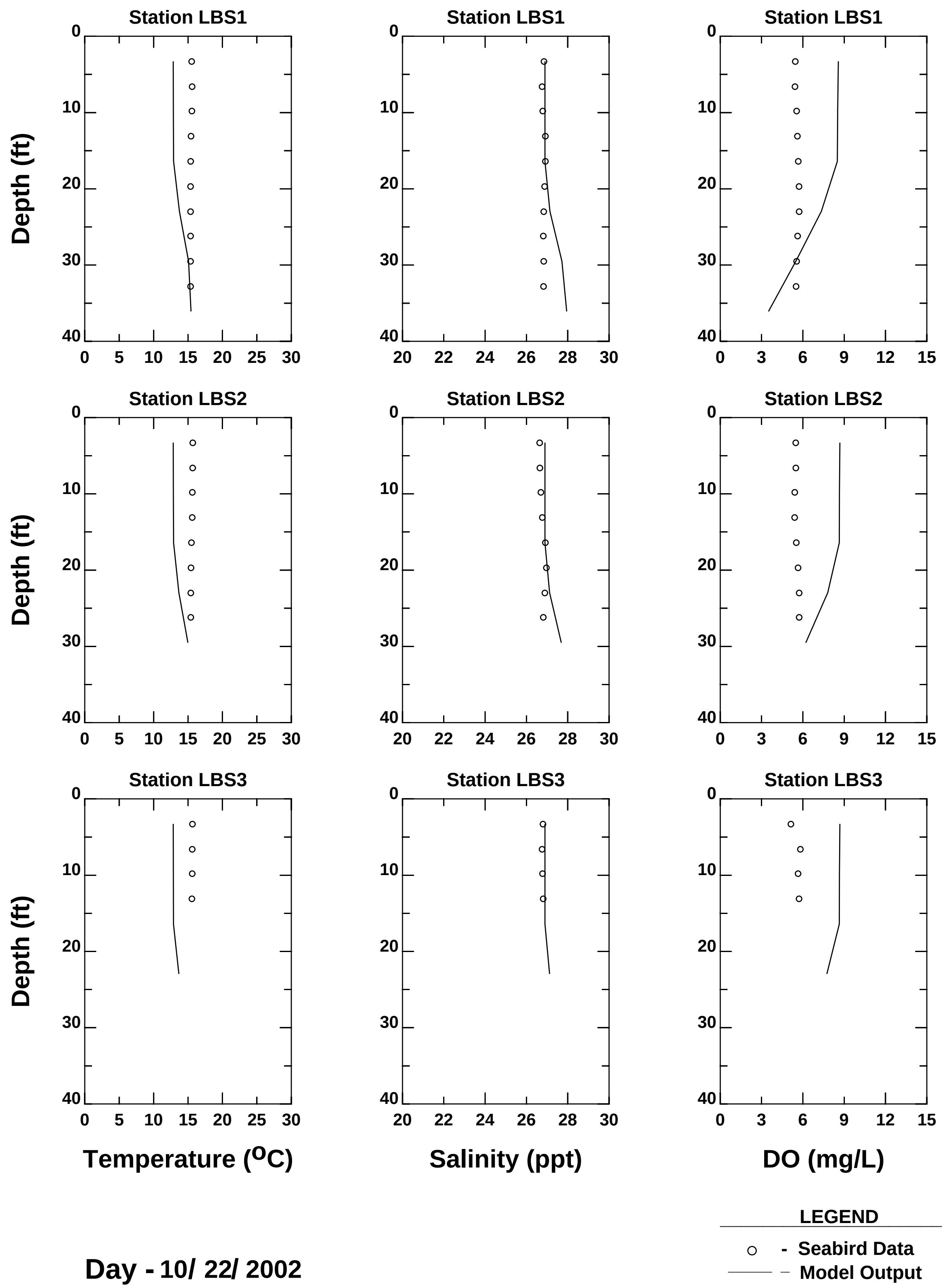

**Day - 7 / 30/ 2002**

**Norton Basin Model, Vertical Profile in Little Bay Shallows**



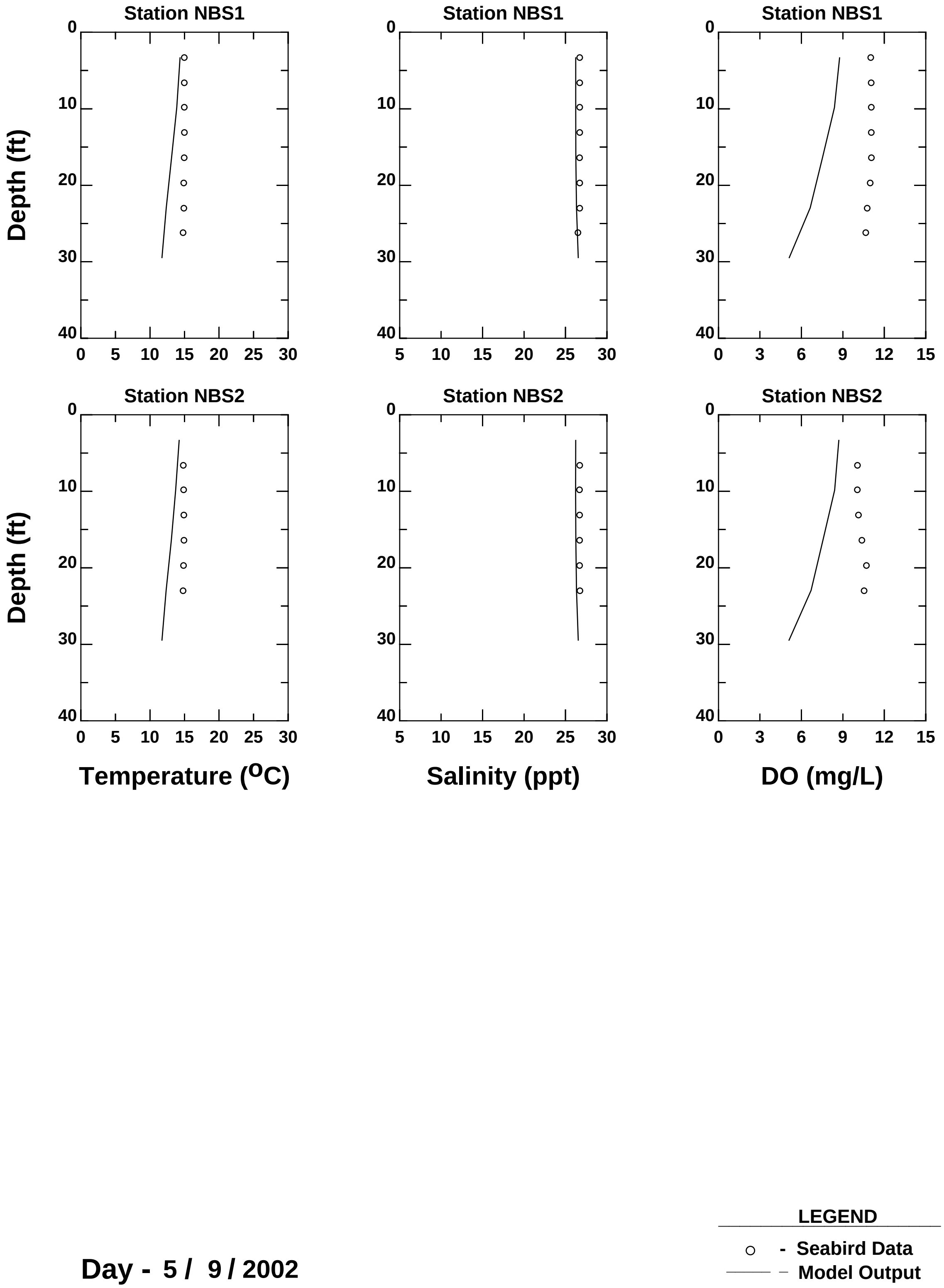

**Day - 9 / 24/ 2002**

**Norton Basin Model, Vertical Profile in Little Bay Shallows**



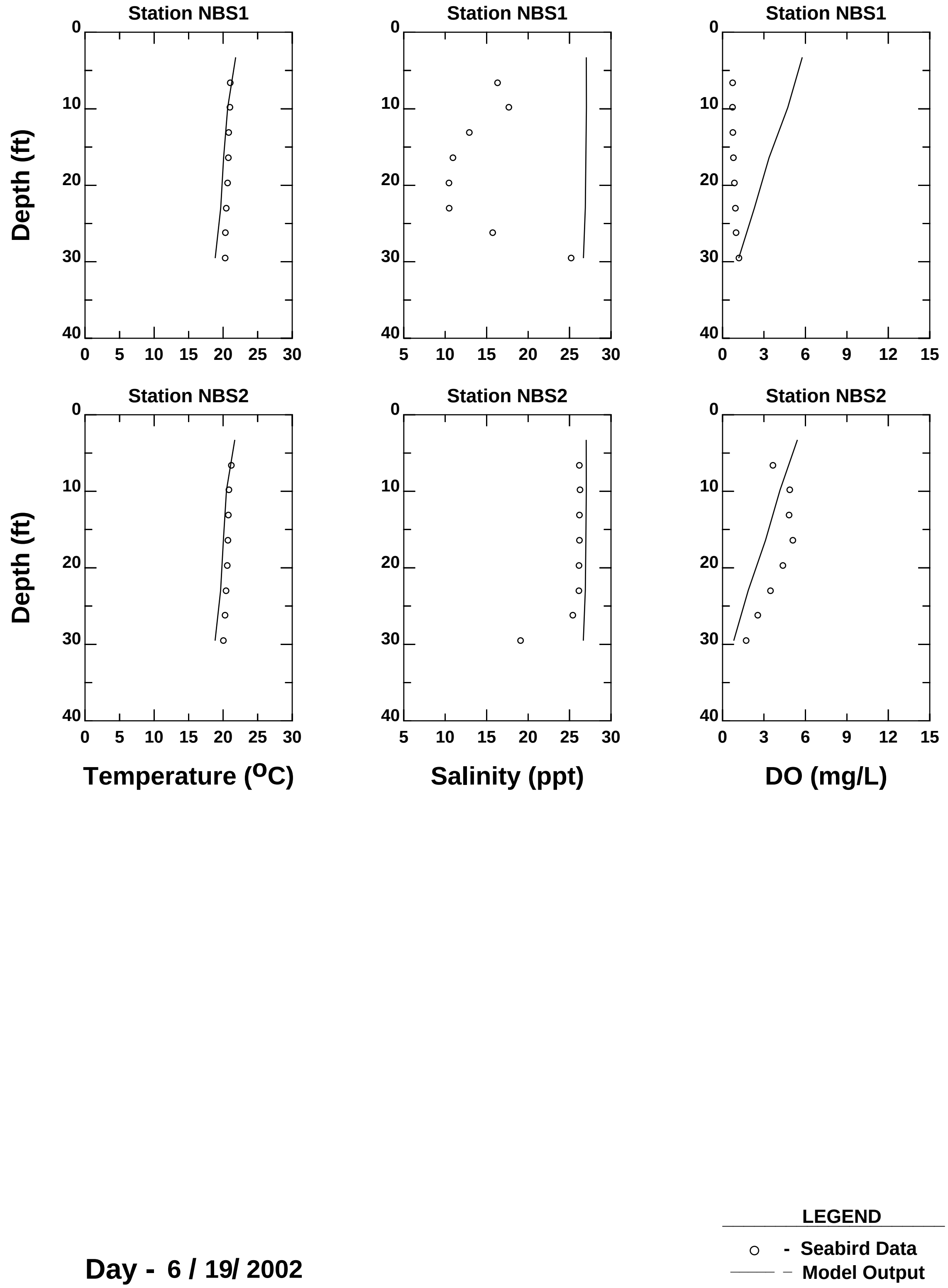

Day - 10/ 22/ 2002

Norton Basin Model, Vertical Profile in Little Bay Shallows



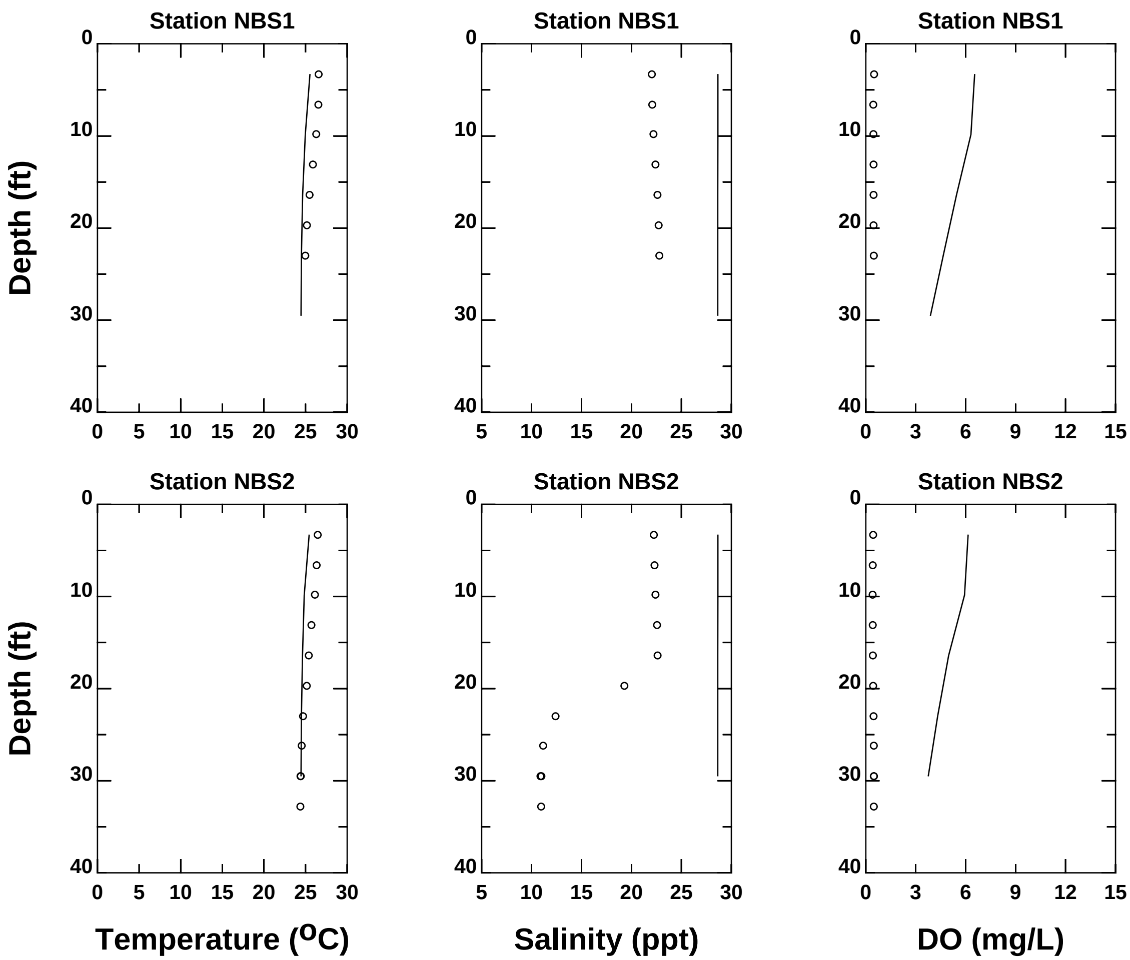

**Day - 5 / 9 / 2002**

**Norton Basin Model, Vertical Profile in Norton Basin Shallows**



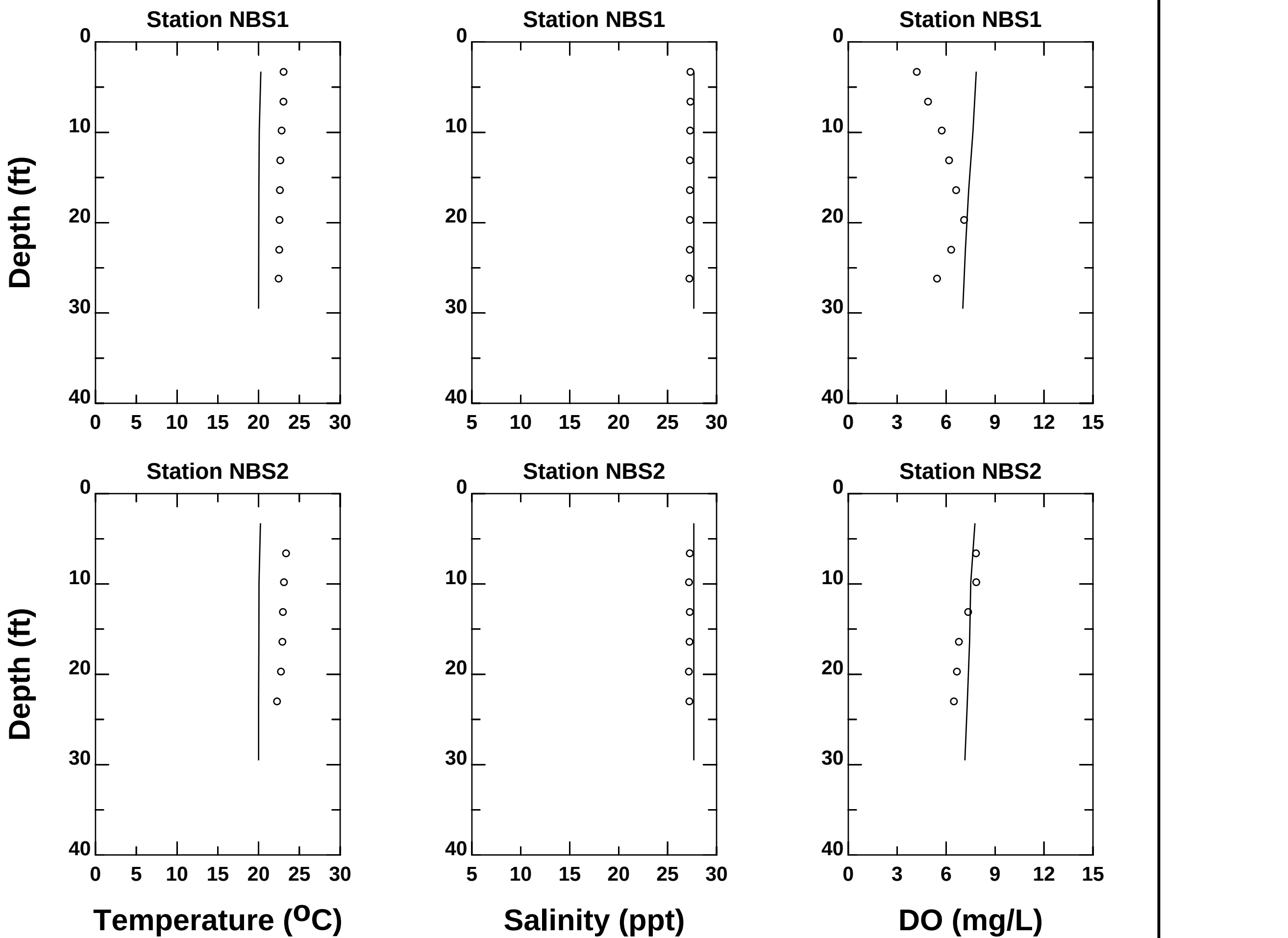

**Day - 6 / 19/ 2002**

**Norton Basin Model, Vertical Profile in Norton Basin Shallows**




Day - 7 / 30/ 2002

Norton Basin Model, Vertical Profile in Norton Basin Shallows

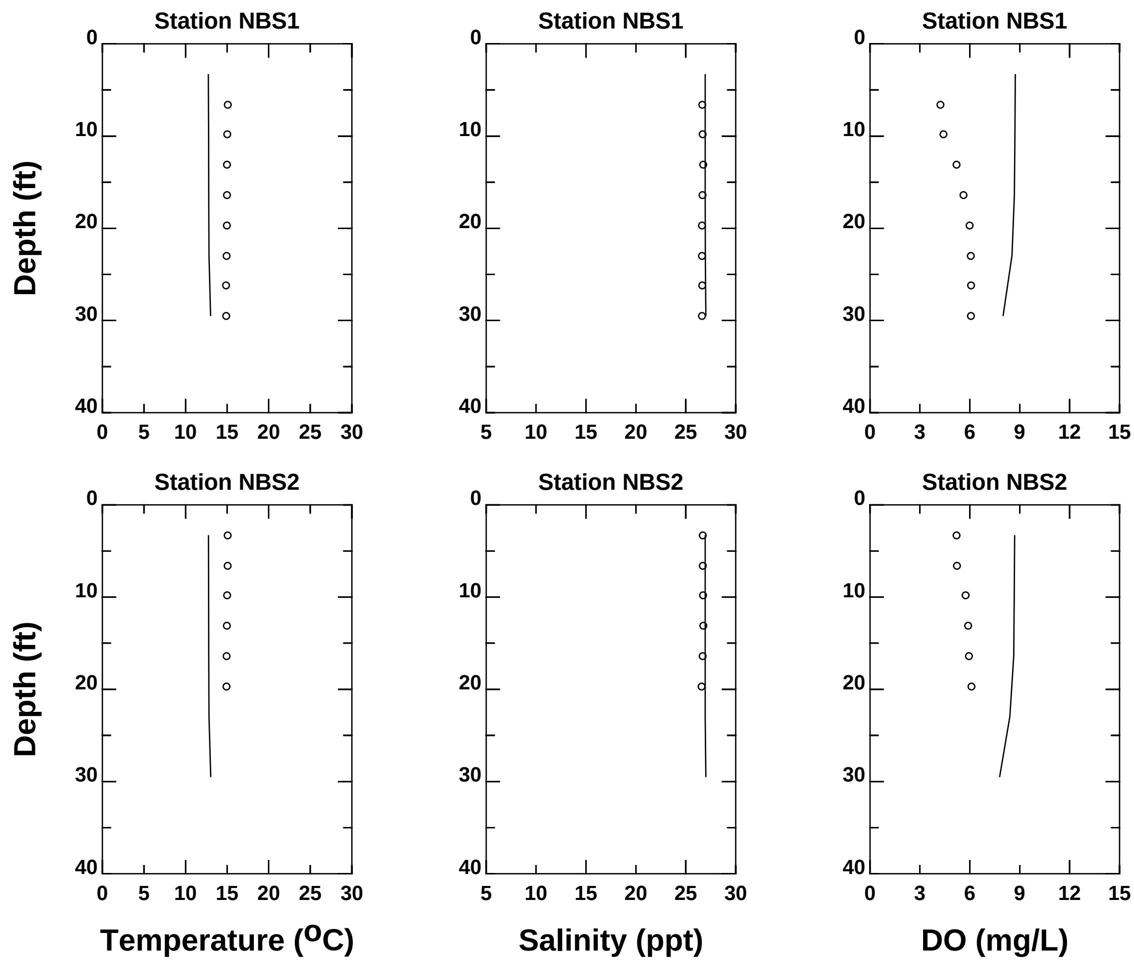



LEGEND

○ - Seabird Data
— - Model Output

Day - 9 / 24/ 2002

**Norton Basin Model, Vertical Profile in Norton Basin Shallows**




Day - 10/ 22/ 2002

Norton Basin Model, Vertical Profile in Norton Basin Shallows